IMPACTS OF WOODY DEBRIS ON FLUVIAL PROCESSES AND CHANNEL MORPHOLOGY IN STABLE AND UNSTABLE STREAMS

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by

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LIST OF CONTENTS

SUMMARY

This report documents the findings of a year long study to asses the impact of Large Woody Debris (LWD) upon channel evolution and morphology in unstable sand bed rivers in northern Mississippi. The aim of this research is to gain an improved understanding of the basin-wide impact of LWD dynamics in unstable and stable channel environments and to develop a set of coherent debris management strategies for erosion control, habitat enhancement, and maintenance/design considerations for run-of-river structures, based upon sound geomorphic and engineering analysis.

Data from the US Army Corps of Engineers Demonstration Erosion Control (DEC) survey program, conducted in May 1995, has been used to locate significant debris jams with respect to planform and long profile data on 23 river reaches in northern Mississippi. The reaches surveyed are between 4000 and 12000 feet long and range in upstream basin area from 3.5 to 150 square miles. A comprehensive understanding of debris dynamics can be attained from surveying these channels because reaches fall into several categories including, stable/unstable reaches, straight/meandering reaches and reaches which have either a predominantly agricultural or wooded riparian zone. The debris jams in each reach have been surveyed in detail to determine the mechanisms and locations of debris input, jam impact upon channel morphology and sediment routing and jam stability over time. The final of these objectives has been assessed by comparing the survey results of the current study with those obtained in the 1994/1995 research effort (see Wallerstein, 1995).

An up to date review of the literature concerning the geomorphic impacts of in-channel LWD, and current LWD management strategies is presented.

Survey and reconnaissance results are presented and analysed. Findings show that the locations of debris input may be predicted using simple geomorphic variables. The frequency of jams and volume of debris appear to only be very weakly related to drainage basin area, composite channel width and unit stream power, which are three potentially predictive independent variables. The distribution of sedimentation and scour associated with debris jams appears to have an explainable distribution when related to drainage basin area. Comparison of May 1994 with May 1995 long profile data sets shows that the majority of jams have remained in place over the intervening period, only minor jams appear to have been displaced and several new jams have been recorded and largely attributed to debris input caused by bank instability

An updated version of the LWD Management Program presented in Wallerstein (1995) is enclosed, on a disk, with this document. A second program is presented here (also enclosed on the disk) which calculates the probability of debris build-up at bridge piers, and the associated debris induced scour, based upon modified theoretical equations published by Melville and Dongol (1992) and Simons and Li (1979).

Preliminary conclusions and management recommendations are made, based upon the findings obtained thus far.

UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

To convert	To	Multiply by
inches (in)	*millimetres (mm)*	25.4
feet (ft)	*meters (m)*	0.305
yards (yd)	*meters (m)*	0.914
miles (Mi)	*kilometres (km)*	1.61
square miles (sq. miles)	*square kilometres (km^2)*	2.59
cubic feet per second (cfs)	*cubic meters per second (cms)*	0.0283

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LIST OF FIGURES

1 INTRODUCTION

There has been increasing interest in the role of vegetation in fluvial geomorphology in recent years because it has been recognised that river dynamics cannot be fully understood without taking into account the impact that vegetation has upon bank stability, flow velocity, and riverine habitat.

As a consequence the study of in-channel Large Woody Debris (LWD) or Coarse Woody Debris (CWD) as it is sometimes referred to (that is trees, branches and other larger organic matter, operationally defined as material with a length greater than 1 metre) and its accumulation as jams or dams and impact upon the channel environment has become a topic receiving increasing research interest over the past 5 to 10 years.

In a review of relevant literature undertaken in an earlier study (Wallerstein 1994) it was established that a large proportion of the research performed to date has been carried out in upland areas, and in stable, gravel bed rivers such as in the Pacific North West (Hogan et. al., 1995; Fetherston et. al., 1995) to determine the impact of LWD on salmon habitat and migration, and in relation to logging operations and forest management. Very little is known about the impact of LWD in sand bed, or unstable rivers. Much of the work is fairly qualitative and observational in nature and there has been little emphasis on determining the key variables at play in LWD dynamics, and the modes of their interaction. Most studies have also been undertaken in isolated reaches, rather than covering basin-wide debris processes, although there are one or two notable exceptions (see Gregory et al., 1993).

At present, LWD management is, therefore, conducted from an incomplete understanding of debris impacts and dynamics and operational maintenance of debris is carried out on an ad hoc basis.

The ongoing aim of this esearch effort is to asses the catchment wide impact of LWD over a wide range of channel sizes but in unstable, rapidly evolving rivers with sand, clay and loess bed and banks. The research in this project has been centred on streams in the DEC (Demonstration Erosion Control) watersheds draining the Bluff Line hills of Northern Mississippi, which are known to be evolving rapidly in response to complex response in the fluvial system following catchment land-use changes and past engineering interventions.

The specific aims of this research are:

1) To collect a large, meaningful data set concerning the reach scale and basin-wide influences of LWD on channel morphology in a different type of channel environment to that which has been studied so far, namely unstable, rapidly evolving sand-bed rivers.

2) To asses whether there are preferential sites of debris input and accumulation within the channel environment and the stability of debris jams in term of there longevity in a particular reach.

3) To investigate how effectively debris jams inhibit or promote bed scour, sediment transport and storage in order to determine wnether they are net stabilising or destabilising elements in the system.

4)To asses the impact of debris at run-of-river hydraulic structures such as grade controls, bridges, bendway weirs, locks and dam sluices.

5) To develop a set of guidelines for in-channel LWD management that could be used by engineers and river managers as an aid to assessment, design and maintenance of stable channels, and guidelines for LWD management technologies at run-of-river structures.

This report presents an up to date review of literature concerning the geomorphological impact of LWD and LWD management strategies.

Data collection was undertaken during a three week survey program in May 1995 with the assistance of the Colorado State University DEC survey crew. A comprehensive reconnaissance survey was made of all debris jams in the 23 study reaches, and each site was also surveyed into the long profile and cross section data to enable comparison with the data obtained in May 1994. Analysis of these data are include within this report.

The geomorphological characteristics of jams in each reach have been analysed and plotted against independent catchment variables, including drainage basin area, stream power and average channel top width to determine whether the geomorphological effects of LWD have a coherent and predictable, spatial relationship. Debris jam sediment budgets have also been calculated and related to spatial parameters to determine whether the net impact of debris jams is sediment retention or sediment scour and mobilisation. An understanding of this factor is important as it will indicate whether LWD is a net stabilising or destabilising agent in sand-bed rivers

This report also contains an updated version of the LWD Management Program that was first presented in Wallerstein (1995)

A second program has also been developed, and is presented here, which calculates the probability of debris build-up at bridge piers, and the associated debris induced scour, based upon modified theoretical equations published by Melville and Dongol (1992) and Simons and Li (1979). These two programs are discussed in chapter 5. The two programs are included on a disk inside the back cover of this report, and user manuals are included in Appendices 1 and 2.

The long-term aim of this research is an improved understanding of the basin-wide impact of LWD dynamics in unstable and stable channel environments and the development of coherent basin-wide debris management strategies for erosion control, habitat enhancement, and maintenance/design procedure for DEC and run-of-river structures, based upon sound geomorphic and engineering analysis.

2 LITERATURE REVIEW

2.1 INTRODUCTION

Organic or woody debris is an important channel independent variable in many fluvial systems (Hogan, 1987). For example, Bevan (1948; quoted in Keller and Macdonald, 1995) concluded that in the Middle Fork Willamette River, Oregon, woody debris was responsible for more channel changes than any other factor.

In a literature review of published material then available, Hickin (1984) suggested that vegetation may influence channel processes through five mechanisms:

a) Flow resistance

b) Bank strength

c) Bar sedimentation

d) Formation of log jams

e) Concave-bank bench deposits

Hogan also identified that the literature concerning this subject was of two main types: that dealing with the indirect influence relations between vegetation, water, sediment yields and river morphology; and that dealing with the direct impacts of channel vegetation on channel morphology.

Since the 1980's the number of papers dealing with vegetation in rivers has increased markedly, however, including a number of studies concerning Coarse Woody Debris (CWD), (Nakamura & Swanson, 1993), Large Organic Debris (LOD) (Hogan, 1987) or Large Woody Debris (LWD), (Smith & Shields, 1992) and its accumulation as jams or dams in river channels.

Studies can be grouped by topic into those dealing primarily with :

a) Input processes, distribution and residence time of LWD

b) Geomorphic significance of LWD

c) Ecological impact of LWD

The physical processes involved in each topic vary depending upon the size of the stream relative to that of the CWD (Nakamura et al, 1993).

Most studies have been carried out in essentially stable channel environments in the US and Canadian Pacific Northwest, the UK, and New Zealand. Instability, in the form of landsliding, is cited by Pearce & Watson (1981) as a means for debris to enter channels, but, more generally, the study of debris impacts in inherently unstable channels has not been addressed.

2.2 INPUT PROCESSES, FORMATION AND RESIDENCE TIME OF LWD

2.2.1 Input Processes

Large Organic Debris enters river systems by two main processes; either from outside the channel due to bank erosion. mass wasting, windthrow, collapse of trees due to ice loading or biological factors such as death and litter fall (Keller, 1979); or from inside the channel, through erosion and flotation of emergent and riparian trees (Hogan, 1987), (Figure 2.1). Fetherston et al. (1995) suggest that debris inputs are either "chronic or episodic". Chronic inputs are frequent but small in magnitude and occur due to tree mortality and bank failure, while episodic inputs are infrequent but provide a large amount of material. Episodic input processes include windthrow, ice storm, fire and flood events. The dominance of different input processes varies widely. For example 45 percent of inputs is due to windthrow in the Lymington Basin, UK (Gregory et. al, 1993), while massive inputs from landsliding of debris in a mountain catchment are reported by Pearce & Watson (1983), and by lansliding as a consequence of logging operations in the Queen Charlotte Island, British Columbia by Hogan et al. (1995). Keller et al. (1979) suggest that in low gradient, meandering streams inputs are predominantly the result of bank erosion and mass bank wasting, windthrow and ice loading, while in mountain streams the main process is debris avalanche. Diehl & Bryan (1994) found the dominant input process to be bank erosion in unstable rivers in Tennessee and noted that channel instability could be a good indicator of in-channel debris abundance. LWD that has been input by bank erosion can be identified and distinguished from that which has entered by other processes because the trees will usually have an asymmetrical root mass due to progressive slipping of the tree from the bank into the channel (Diehl & Bryan, 1994). Smith et al., (1993) found debris input to be spatially random. However, the locations of zones from which LWD is supplied will vary as a function of the distribution of riparian vegetation, streamside topography, channel characteristics and the prevailing wind strength and direction, (Fetherston et al., 1995). It may therefore be possible to determine which are the dominant input factors based on observations of these factors and, thereby, predict the distribution of major source areas within the catchment.

2.2.2 Formation of Jams

Once in a channel, debris may form into jams or dams. Jams usually form around "key coarse woody debris" (Nakamura, 1993), which are usually large, whole trees that have entered the channel by one of the mechanisms mentioned above and which may be anchored to the bed or banks at one or both ends. Smaller debris floating down the channel then accumulates against the key elements, which acts as a sieve to debris d, later to sediment. If there is no fine debris in the stream a mature jam may ever form, so that the impact of key-debris is minimal. The location of debris jams within the channel, their size and their coherence vary as functions of position in the catchment. In small streams much debris will accumulate where it falls because the flow is not competent to move coarse material, and it is in larger streams that distinct jams may form. In yet larger rivers debris may never accumulate because it is carried away downstream. Piegay (1993) observed debris distribution in a sixth order river in France and found that most material was deposited on the channel margins, forming a narrow debris line rather than in-flow jams. Wallance & Benke (1984) noted a similar distribution in meandering rivers in the south east USA where dense, partial jams formed at a angle to the main flow. As mean channel dimensions and flow competence increase downstream more and more debris will be moved from its position of input, until all but the largest trees are transported. This process relationship may result in a trend of reducing LWD frequency downstream, but, at the same time, an increase in the volumetric size of each jam (Swanson et. al., 1982).

2.2.3 Residence time of debris jams

The residence time, or persistence, of debris jams is an important factor, which determines the timespan over which channel morphology at a jam site will be affected. The influence exerted by jams on channel morphology also varies with time as the debris in the jam structure deteriorates (Hogan et. al., 1995). Assessing residence time is difficult and estimates range between 12 months, for a 36% change or removal (Gregory & Gurnell (1985), to 40-90 years (Hogan, 1987), to 200 years for streams in British Columbia (Keller & Tally, 1979). Residence times may vary as a function of drainage basin area, and are largely dependent upon the return period of a flood with a magnitude which is capable of entraining a significant proportion of the trapped debris or moving larger key components of the jam. Other important factors affecting jam persistence are average tree dimensions and wood deterioration rate. Swanson et al. (1982) discovered that the density and volume of in-channel debris are greater in rivers which flow through coniferous forests, than it is in those that flow though deciduous forests. This is because conifers are, on average, taller and have slower decay rates than deciduous trees

Figure 2.1 Dynamics of woody debris (adapted from Keller & Swanson, 1979)

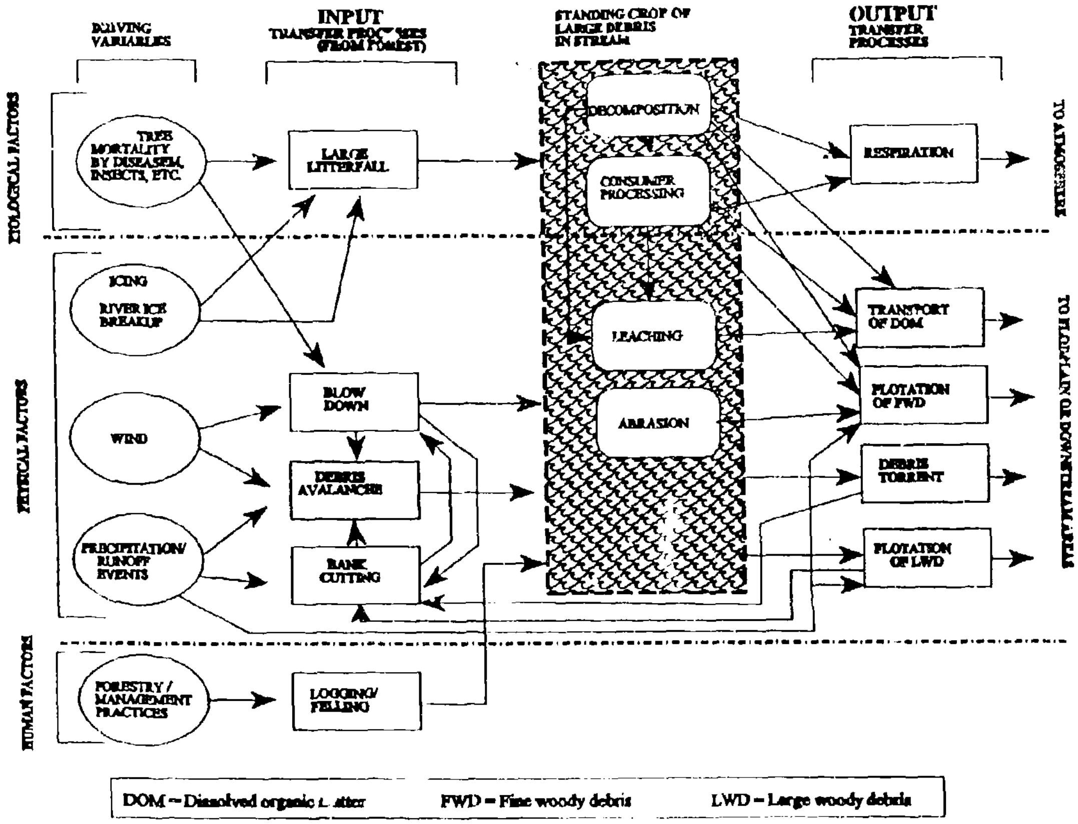
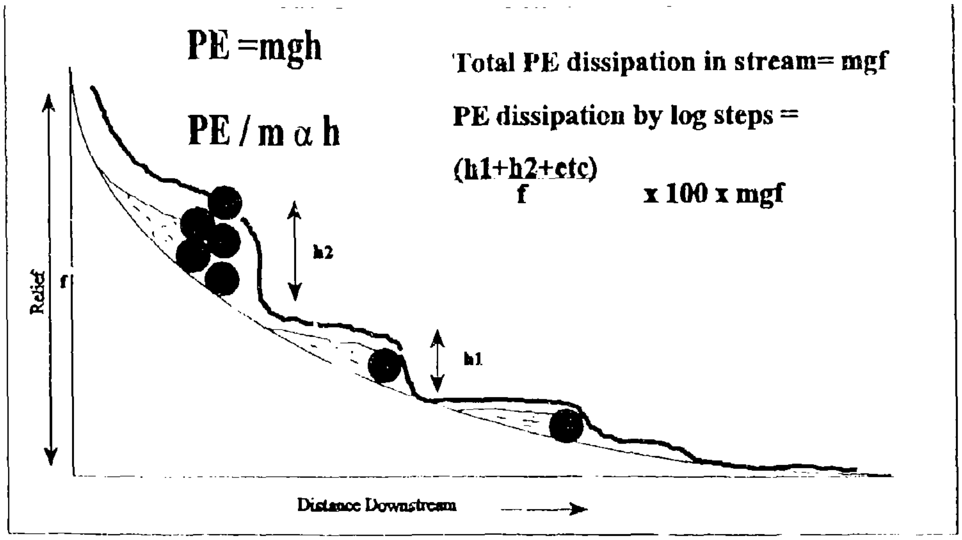
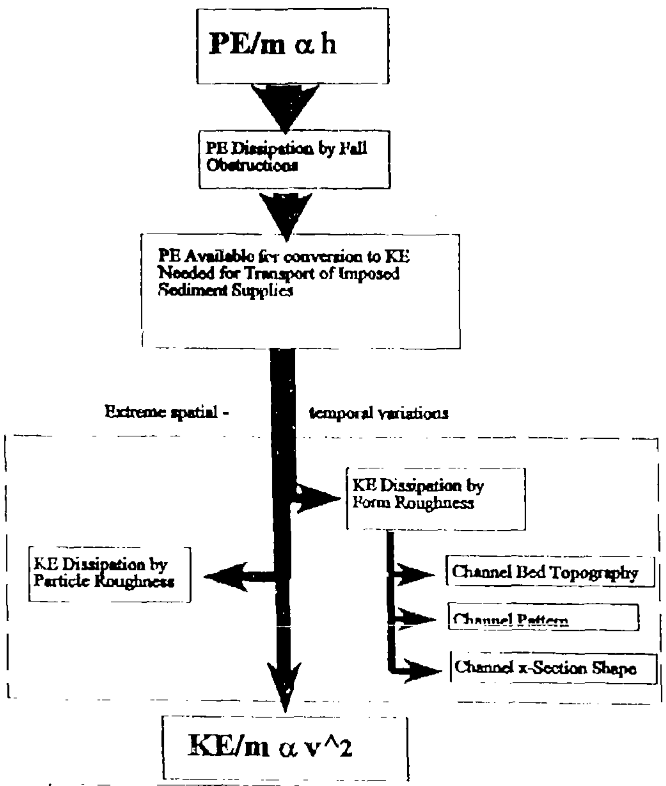


Figure 2.2 Energy transformations in streams with log steps (adapted from Marston, 1982)



Potential stream energy per unit mass of water (PE/m) is directly proportional to h, or the relief in a specific stream.
PE dissipation by log steps = Cumulative change of water surface elevation (h1+h2+ etc) as a percentage of total stream relief (f)



Log steps cause a reduction in potential energy that would otherwise be converted to a longitudinal component of kinetic energy actually used for sediment transport (PE/m = potential stream energy per unit mass of water; KE/m = kinetic energy per unit mass of water; h = relief in a specific segment; v = stream velocity

2.3 GEOMORPHIC SIGNIFICANCE OF LWD

2.3.1 Effects of channel scale

It is important to recognise that processes are scale dependent and that the influence of LWD on channel and valley morphology may change systematically downstream through the network (Abbe & Montgomery, 1993). Zimmerman et al. (1967) found that debris accumulations in a very small stream completely obscured the usual hydraulic geometry relations, while Robinson & Beschta (1990), and Keller & Tally (1979) suggest that debris loadings increase with stream size. Gregory et al. (1985), have characterised jams into three types :

1) Active (form a complete barrier to water and sediment movement, and create a distinct step or fall in the channel profile)
2) Complete (a complete barrier to water/sediment movement, but no step formed)
3) Partial (only a partial barrier to flow)

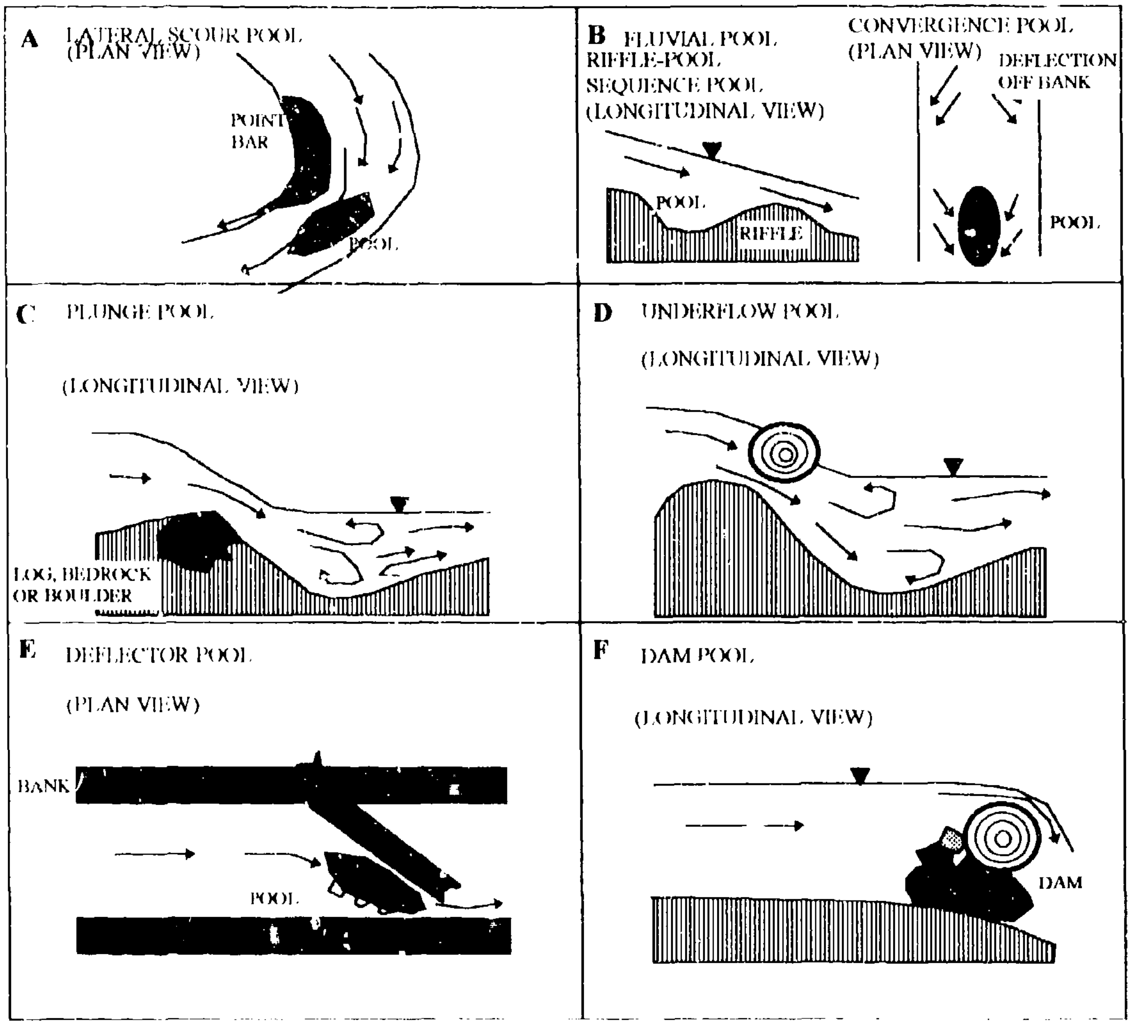
They suggest that these types become sequentially more prevalent as channel size increases. Once trees fall into a stream, their influence on channel form and process may be quite different from that when they were on the banks, changing from stabilising to destabilising through causing local bed scour and basal erosion of the banks. Thus, jams represent a type of auto-diversion, that is, a change in channel morphology triggered by the fluvial process itself (Keller & Swanson, 1979). The type and degree of impact on channel morphology depends primarily on the channel width/tree height ratio and on debris orientation relative to the flow. Mean discharge and the dominant discharge recurrence interval are also important because the higher the flow is relative to jam size, the smaller will be the jam's impact in terms of acting as a flow diverter and roughness element. The principal effects of debris upon channel morphology are described below.

2.3.2 Impact of debris jams upon channel morphology

LWD influences the geomorphology of rivers on three levels (Gray, 1974); the overall channel form; detailed features of the channel topography; and channel roughness.

Heede (1985), Smith (1993), Andrus et al. (1988) and Mosley (1981) have all observed that the spatial distribution and number of pools, riffles and gravel bars is positively related to the distribution and volume of LWD in the channel. This relationship has been explained through laboratory experiments by Smith & Beschta (1994), who found that the pool-riffle sequence in

Figure 2.3 Schematic diagrams of pool types (Modified from Robinson and Beschta, 1990)



gravel-bed rivers is maintained by a combination of mean boundary shear stress and intermittent lift and drag forces due to velocity fluctuations around debris. Random debris input will also distort the pool-riffle sequence, making it less systematic, so that the long-profile has very little spatial memory, or periodicity (Robinson & Beschta, 1990) Robinson and Beschta (1990) devised a pool classification system, containing six pool categories (lateral scour, fluvial, plunge, underflow, deflector and dam) based on flow and debris interaction (see figure 2.3). Other studies have shown that a considerable proportion of the vertical fall of channels can occur at the sites of debris jams, accounting for a 4% of the vertical drop along a 412m reach of channel in Vermont (Thompson, 1995) and 60% of the total drop in Little Lost

Man Creek in Northern California (Keller & Tally, 1979). Debris jams, therefore, act as local base levels and sediment storage zones which provide a buffer in the sediment routing system (Heede, 1985, Bilby, 1981). Thompson (1995) found that LWD causes an important negative feedback mechanism, where, in the case of channel degradation, there is an increase in debris input due to mass bank failure, which in turn causes greater sediment storage. Channel bed elevation is consequently raised once more and the rate of bank failure and debris input is thereby reduced. On this basis, Klein et al. (1987) argue that jam removal can reduce the base level for the channel upstream and may trigger bank erosion. However, in an experimental study by Smith et al. (1993a and b) it was found that, while the removal of debris from a small gravel bed stream initially caused a four fold increase in bed load transport at bankfull flow, the associated loss of scour turbulence and greater flow resistance imparted by alternate bars actually resulted in a reduction in stream power which was compensated for by sediment deposition and net channel aggredation.

Potential energy is dissipated at jams, with energy loss being as much as 6% of total potential energy (MacDonald et al., 1982). Shields & Smith (1992) found that the Darcy-Weisbach friction factor was 400 % higher at base flow in an uncleared river reach compared to a clear condition, but that this value declined to 35% at high flows. The velocity distribution is also far more heterogeneous in debris-filled reaches, especially at low flow. Changes of stream power distribution due to flow resistance effects in turn give jams the ability to influence the location of erosional and depositional processes. Also the backwater effect created by jam back-pools may induce local silting (Keller et al. 1976). Thus, in small, stable channels, log steps generally increase bank stability and reduce sediment transport rates by creating falls, runs and hydraulic jumps.

Figure 2.2 shows how potential energy is lost through a log-step sequence as outlined by Marston (1982). The localised dissipation of energy can, however, result in associated local scour and bank erosion which causes channel widening. Bank failure may also occur through flow diversion around a debris obstruction (Murgatroyd & Ternan, 1983). Davis & Gregory (1994) have also suggested a mechanism whereby bank failure is induced through the erosion of a porous, gravel, bank subsurface due to the greater hydrostatic pressure caused by debris dammed flow. Conversely, Keller & Tally (1979) have observed, that flow convergence under logs may cause channel narrowing, with sediment storage upstream and a scour-pool downstream of the log step.

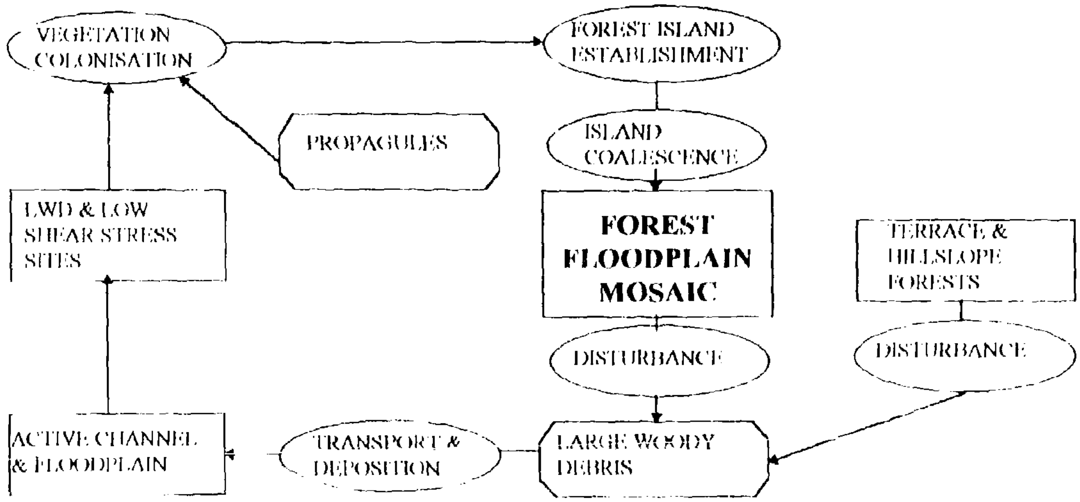
As drainage area increases, and the channel width/tree size ratio exceeds unity, flow is diverted laterally, inducing bank erosion through local basal scour. Hogan (1987) found that in undisturbed channels in British Columbia organic debris orientated diagonally across the channel resulted in high width and depth variability. However, in catchments where there had been logging operations the majority of in-channel discarded timber was orientated parallel to the flow and it subsequently became incorporated into the stream banks, protecting them from erosion. Nakamura & Swanson (1993) and Keller & Swanson (1979) have suggested that there is a progression of types of interaction between debris jam and channel processes, ranging from local base level control and possible local widening in low-order streams, to lateral channel shifts and even meander cut-off in middle-order channels, where debris is moved into larger more coherent jams which may either increase or decrease the channel stability depending upon the erodibility of bed and banks. In larger channels still, bars may form and flow bifurcate around debris obstructions. This last process has been documented by Nanson (1981) in British Columbia, who found that organic debris deposited at low flow provided the nuclei for development of scroll bars, through the local reduction of stream power. Hickin (1984) also observed crib-like bar-head features, but was undecided regarding whether the debris caused bar formation, or whether the bars pre-dated and trapped the debris. In either case, organic debris would, at the very least, enhance sediment deposition and bar formation.

2.4 ECOLOGICAL IMPACT OF LWD

LWD dams are very important in small stream ecosystems because they provide a source of organic matter and retain floating leaves and twigs in the dam structure and backwater pools. This coarse particulate organic matter (CPOM) is broken down in the low energy pool environment by shredder invertebrates, creating fine particulate organic matter (FPOM) and dissolved organic matter (DOM), which are the required energy sources of a succession of invertebrate species who are, in turn, the energy source of high fauna species. Bilby & Likens (1980) found that the percentage of the standing stock of organic matter retained by jams changed from 75% in first order, to 58% in second order, to 20% in third order streams because the prevalence of dam type jams declined downstream. The volume of CPOM therefore declines downstream, while the volume of FPOM and DOM increases. This gives rise to a spatially varied invertebrate community, changing from shredders in small channels to gathers of FPOM downstream. Smock et al. (1989) and Wallance & Benke (1984) found similar correlations between debris volume and invertebrate abundance in sand-bed streams, where debris provides the only stable substrate for organic matter retention and invertebrate habitat. Higher species, such as fish, use debris and associated pools for shade, protection from predators, feeding and spawning grounds. The pools and falls created by log steps also help to oxygenate the flow, and provide a variety of different energy environments which are can be colonised by niche species.

In addition to providing essential fauna habitat, LWD is also a vital factor in the development of the riparian forest mosaic (Fetherston et. al., 1995). Debris deposition in the channel and on the floodplain creates sites of low boundary shear-stress where vegetation colonisation can take place. This leads to the development of vegetation stabilised islands and bars (affecting the geomorphological development of the channel) which may subsequently coalesce and/or become attached to the bankline to form new areas of forested floodplain that provide shade, bank stability and supply and storage of organic matter, sediment, water and new LWD. Figure 2.4 shows a modified version of the LWD-driven model of Fetherston et al., (1995) for riparian forest development, based upon research findings from the Pacific Northwest.

Figure 2.4 Conceptual model of montane riparian forest development. (Modified from Fetherston et al., 1995)



2.5 MANAGEMENT STRATEGIES

Until basic research concerning in-channel LWD began to suggest otherwise, it was commonly believed that LWD was detrimental to the fluvial system, hydraulically, ecologically and geomorphically. On this basis, reasons for debris removal included :

a) To improve navigation;

b) To increase channel conveyance by reducing roughness;

c) To eliminate bank erosion;

d) To facilitate the migration of fish, especially salmon (MacDonald, 1982).

It is now recognised that there are advantages to be gained by maintaining or even increasing in-channel debris accumulations (Gregory & Davis, 1992; Keller & McDonald, 1995). Management strategies that are currently advocated vary widely, however. This perhaps reflects our, as yet, incomplete understanding of LWD dynamics in different channel environments, and because goals vary between different management strategies. In this respect effective debris management depends on the underlying aims of the proposed management action.

Successful management also depends upon a comprehensive understanding of the following hydrogeomorphological factors (Gregory & Davis, 1992)

a) The relationship between river channel processes and river channel morphology;

b) Awareness of the timescales over which river channels may adjust;

c) Consideration of channel management in the wider context of river basin management

More specifically, debris management must consider :

a) Channel stream power characteristics;

b) Sediment movement and storage relationships (high/low; fine/coarse sediment; suspended/bedload);

c) Channel stability;

d) Size and character of river channel in relation to debris size;

e) Spacing and frequency of jams;

f) Size and character of jams, and orientations of component material;

7) Age and stability of component materials.

In an evaluation of soft engineering for instream structures, including some using woody debris, to mitigate the effects of highway construction in British Columbia, Miles (1995) found that nearly 50% of the structures had been severely damaged after 8 to 14 years. Miles attributed this problem to insufficient understanding and consideration of the stability of the structures in a high energy river environment. He concludes that soft restoration techniques may not be appropriate in highly energetic mountain rivers, and that if restoration is to be performed, funding must be made available for long term monitoring and maintenance.

There appears, in general, to be a consensus of opinion amongst researchers interested in LWD regarding appropriate management approaches for channel restoration. Bren (1993) and Nunnally (1978) argued that the riparian zone should be left undisturbed, in a natural state (although defining natural is difficult in most channels), and that, because debris is so important for the river ecosystem, debris jams should be left in place. Keller and McDonald (1995) studied catchments which had been disturbed by logging operations. They recommended that a riparian buffer strip should be left to maintain the natural LWD supply and warned that landsliding events caused by badly controlled logging operations, can cause excessive LWD input which is detrimental to stream habitat and flow and sediment conveyance. There may be a case in streams lacking a wooded riparian strip for the introduction of debris jams (Keller & McDonald, 1995). If a debris recharge policy is to be implemented, however, it is important that debris jam volume and orientation emulates the values which would be found under natural conditions (Robinson & Beschta, 1990). Wallace & Benke (1984) concluded that, in most instances, the best management is probably no management except where adjacent floodplains have to be protected from flooding.

Comprehensive studies of coarse woody debris in relation to river channel management have been carried out by Gregory and Davis (1992) and Gurnell and Gregory (1995a and b). The collation of analyses from twenty two research papers with primary field studies carried out in the New Forest, UK, Gregory & Davis (1992) demonstrated the significance of LWD to channel morphology, processes and ecology (Figure 2.5) and produced a preliminary table of debris management criteria based upon their findings (Figure 2.6). They conclude that "... a conservative approach to debris removal should be adopted for most areas, but that different strategies are needed according to the characteristics of particular localities" (Gregory and Davis, 1992, pg. 133).

It should be noted, however, that this study, in common with most others cited, was carried out in an essentially stable, equilibrium channel environment where changes to channel morphology are negligible and significant impacts relate mostly to ecological habitat diversity.

Also, little attention is paid to "different strategies" that may be required in contrasting channel environments and there is no discussion of conflicts between practices advocated by various organisations in the USA. For example, Gregory & Davis (1992) suggest that, based on their literature survey, no debris should be removed from channels exhibiting low stability (Figure 2.7). However, this contradicts the practice described by Brookes (1985, pg. 64), "In North America the concept of channel restoration was developed in North Carolina under the funding of the Water Resources Research Institute of the State University ...Restoration is achieved by removing debris jams and providing uniform channel cross-sections and gradients whilst preserving meanders, leaving as many trees as possible along the stream banks, and stabilising banks with vegetation and rip-rap where necessary ...".

Similar approaches, have been documented and carried out by numerous researchers and organisations in the USA, including; McConnel et al. (1980), based upon work on the Wolf River, Tennessee; the American Fisheries Society (1983), in a publication entitled "Stream Obstruction Removal Guidelines", (see Figure 2.8); Shields and Nunnally (1984); and Palmiter (Institute of Environmental Sciences, 1982).

The recommendations of Palmiter (1982) include the following :

a) Removal of log-jam material by cutting it to a manageable size;

b) Protection of eroding banks using brush piles and log-jam material, with rope and wire;

c) Removal of sand and gravel using brush-pile deflectors;

d) Revegetation to stabilise banks and shade-out aquatic plants;

e) Removal of potential obstructions such as trees and branches;

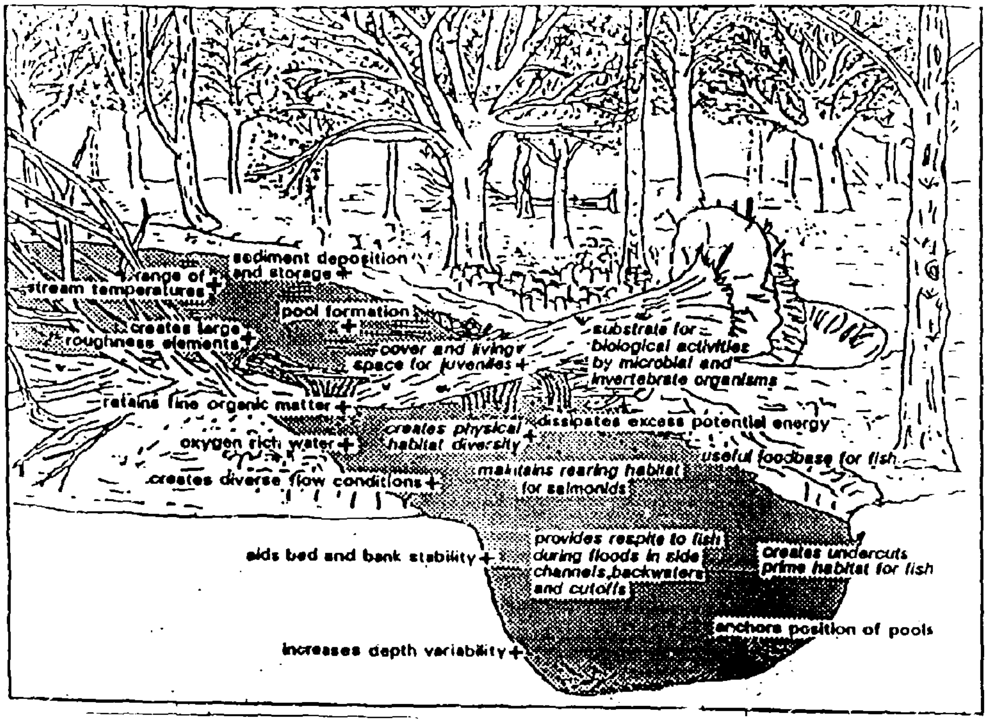
Willeke & Baldwin (1984) assessed the Palmiter techniques and found them suitable for areas experiencing chronic, low intensity flooding and bank erosion, but not advisable for rivers with extreme flood problems. They are also found to be largely ineffective for erosion control where the mechanism of bank failure is that of mass wasting rather than tractive force erosion (Hasselwander, 1989).

It is evident from the preceding discussion of LWD management strategies that recommendations vary considerably, from limited or no interference, to total clearance of debris from the channel. These apparently contradictory recommendations must be viewed in the light of the overall management programme that they were designed for, as requirements for habitat enhancement differ from those for flood defence.

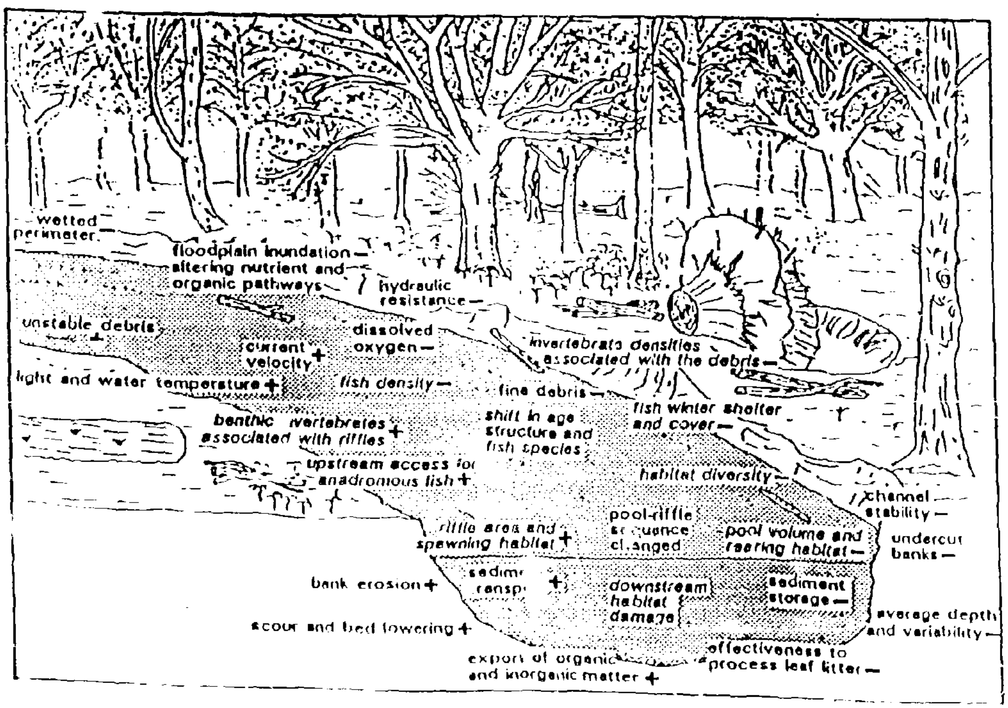
Finally, and of great importance, is the fact that the recommendations of type made by Palmiter and others, address debris management predominantly in, low gradient, sand-bed, and perhaps unstable, flood prone rivers (South East USA), while those prescribed by Gregory and Davis (1992) and others are based upon findings from upland, even montane, gravel-bed rivers and streams (Pacific Northwest USA). Process relationships between the debris and the channel are likely to differ between these two types of fluvial environment, although, as yet, these differences have not been recognised or investigated. Indeed, while there is a wealth of research concerning the geomorphological impacts of LWD in upland gravel-bed rivers, there has been little comparable research in lowland, sand-bed, and/or unstable river environments.

Figure 2.5 The significance of coarse woody debris dams for channel morphology, channel processes and ecology (modified from Gregory and Davis, 1992)

DAM PRESENT



DAM REMOVED



Characteristics which relate to ecological habitats are shown in italics

Figure 2.6 Determinants for a management strategy for rivers in woodland areas (modified from Gregory and Davis, 1992)

	CHANNEL VARIABLE	MANAGEMENT STRATEGY: CHANNEL CLEARANCE	PARTIAL DEBRIS CLEARANCE	NO REMOVAL	LIMITED DEBRIS CLEARANCE
CHANNEL ENVIRONMENT	Stream Power		◄	high	►
		◄	low		►
	Sediment Storage and Transport		◄	high	►
		◄	low		►
	Channel Width / Tree Height	◄	high > 1	►	
			◄	low < 1	►
	Channel Stability	◄	high		►
				◄ low	►
	Adjacent Landuse Value	◄ high value agricultural ►	◄ grazing ►	◄ managed / old growth forest	►
DEBRIS ENVIRONMENT	Spacing and Frequency of Dams	◄ excessive ►	◄ high ►	◄ natural levels ►	◄ low > 5 - 10 channel widths ►
	Debris Budget Loading	◄ excessive ►	◄ high ►	◄ natural levels ►	◄ low ►
	Size and Character of Coarse Debris	◄	< 10 cm diameter	►	
			◄	> 10 cm diameter	►
		◄	green foliage ►		
	Size of Blockage	> 10 channel widths long, debris jam	> 5 channel widths long	active debris dam	partial debris dam
	Anchorage of Debris	◄ no anchorage ►	◄ single end anchorage ►	◄ both ends anchored	►
	Stability of Debris	◄ low ►	◄ moderate ►	◄ high	►
	Orientation of Debris to Flow	◄ 60-90 degrees	►	◄ parallel to flow	►
	Residence Time of Logging Debris	◄ 24 hrs	►	◄ > 5 yrs since introduction	►
IMPACTS	Habitat Diversity	◄ low	►	◄ high ►	◄ needs enhancing ►
	Aesthetics	◄ low importance	►	◄ high importance	►
	Blockage to Fish Migration	◄ possible	►	◄ negligable	►

Figure 2.7 Definition of Stream Obstruction Conditions (Modified from American Fisheries Society, 1983)

Condition One These stream segments have acceptable flow and no work would be required. They may contain various amounts of instream debris and fine sediment, such as silt, sand, gravel, rubble, boulders, logs and brush. In certain situations flow may be impeded, but due to stream and land classification or adjacent land use, this is not a problem	**Management Criteria** No work to be conducted.
Condition Two These stream segments currently have no major flow impediments, but existing conditions are such that obstructions are likely to form in the near future, causing unacceptable problems. This condition is generally characterised by small accumulations of logs and/or other debris which occasionally span the entire stream width. Accumulations are isolated, not massive and do not presently cause upstream ponding damage.	**Management Criteria** Equipment that will cause the least damage to the environment shall be selected for performing the work. First consideration will be given to the use of hand operated equipment such as axes, chain saws, and winches to remove accumulations. Boats with motors may be used where needed. When the use of hand operated tools is not feasible, heavier equipment may be used, e.g. small tractors, backhoes, bulldozers, log skidders and low PSI equipment. Equipment shall be operated in a manner that results in least damage to vegetation and soils of the project area. In some cases explosives may be used resulting in less damage. Debris designated for removal from the stream or floodway should be removed or secured in such a manner as to restrict its re-entry into the channel. Generally, it should be positioned so as to reduce flood flow impediment
Condition Three These stream segments have unacceptable flow problems. Obstructions are generally characterised by large accumulations of lodged trees, root wads, and/or other debris that frequently span the entire stream width. Although impeded, some flow moves through the obstruction. Large amounts of sediment have not covered or lodged in the obstruction	**Management Criteria** Equipment limitations will be the same as for condition two segments. Work shall be accomplished within the channel or from one side of the channel where possible. Selective tree clearing shall be limited to the minimum necessary for equipment access and efficient operation of equipment on the worked side of the channel. Disposal of equipment may be accomplished by removing it from the floodplain or by burning, burying or piling, as appropriate, with the least amount of disturbance to vegetation. Piled debris [illegible] be gapped at frequent intervals and at all tributaries [illegible] distributaries.
Condition Four These stream segments are characterised by major blockages causing unacceptable flow problems. Obstructions consist of compacted debris and/or debris that severely restricts flow	**Management Criteria** Blockage removal may employ any equipment necessary to accomplish the work in the least damaging manner. Work should be accomplished from one side of the channel where practical. Material shall be disposed in accordance with guidelines presented above for condition three segments. Spoil piles should be constructed as high as sediment properties allow. The placement of spoil around the base of mature trees should be avoided.
Condition Five These stream segments posses unique, sensitive, or especially valuable biotic resources and should be dealt with on a case-by-case basis. Examples include, but are not limited to: Areas harbouring rare or endangered species, shellfish beds, fish spawning and rearing areas, and rookeries.	**Management Criteria** Special provision for protecting unique, sensitive, or productive biotic resources shall be developed by appropriate professionals on a case by case basis.

3 RESEARCH METHODS

Field data collection for the current project was carried out in May/June 1995 with the co-operation of the DEC survey crew from Colorado State University. Twenty three channel reaches were surveyed in the DEC monitoring catchments, which are located in the Yazoo Basin, northern Mississippi. Figure 3.2 shows a geological map of Mississippi with the DEC project area marked. Figure 3.3 shows the rivers and major catchments of the project area in more detail.

Reaches, of between 4000 and 12000 ft, were surveyed on the following creeks :

Nolehoe Creek	Sarter Creek	Lick Creek
Burney Branch	James Wolf Creek	Long Creek
Sykes Creek	Hotopha Creek	Fannegusha Creek
Worsham Creek (East)	Worsham Creek (Middle)	Worsham Creek (West)
Abiaca Creek	Harland Creek	Red Banks Creek
Otoucalofa Creek	Coila Creek	Lee Creek
Perry Creek	Hickahala Creek	Marcum Creek

A full description of the DEC monitoring site characteristics is given in Watson et al. (1993). These surveys provided a comprehensive data-set, which not only covers a range of drainage basin areas, from 4 to 100 miles square, but also allows comparison of debris loadings between reaches with wooded and agricultural riparian zones, between straight and meandering reaches and between highly unstable and stabilising or equilibrium reaches.

Debris jam sites have been surveyed into the thalweg and cross section data for each creek so that there position and associated changes in local channel geomorphology can be monitored over time. Data from the current survey has been processed and overlaid and compared with that collected in May 1994 so that an assessment can be made of the rate of debris input, of the longevity of jams and therefore their effectiveness as geomorphological channel controls, and the changing patterns of associated sedimentation and erosion.

Geomorphological reconnaissance was also carried out at each jam site to document the volume of debris in each jam, its mode of input into the channel, to determine the jam type in terms of impact upon flow pattern and erosion, and to measure the volume of sediment retained in backwater areas or bars. The following variables were assessed at each jam site:

1) Debris jam volume : Estimated volume of woody material (m^3) in each jam, values are then summed for each survey reach.

2) Morphological classification : A debris classification system, modified from one developed by Robinson and Beschta (1989), which describes the geomorphological impact of debris jams throughout the drainage network. Figure 2.3 shows the original classification scheme and figure 5.1 shows the modified version. Jam classification types are as follows:

Underflow jams : In small catchments where fallen trees span the channel at bank-full level. Local bed scour may occur under debris at high flows, otherwise the in-channel geomorphic impact of the LWD is minimal.

Dam jams : In channels where the average tree height to channel width ratio is rough equal to one, so that debris completely spans the channel cross-section. This type of jam causes significant local bank erosion and bed scour due to flow constriction, and backwater effects will cause sediment deposition in the lower energy environment upstream. Bars may also form immediately downstream of the jam.

Deflector jams : Found where input debris does not quite span the channel so that flow is deflected against one or both of the banks causing localised bed scour and bank erosion. Subsequent bank failure results in the input of new LWD material to the reach so that the jam builds up further. Backwater sediment wedges and downstream bars may form at this type of jam provided that stream power is dissipated by the jam below the critical level for the bed load and suspended sediment transport.

Flow Parallel jams : Found where channel width is significantly greater than the key-debris length, and flows are competent enough to rotate debris so that it lies parallel to the flow. Debris is also transported downstream in high flows and deposited against the bank-base on the outside of meander bends or at channel obstructions such as man-made structures. Related bank erosion and bed scour will be minimal, and bank toes may even be stabilised by debris build-up. Flow parallel debris may also initiate or accelerate the formation of mid-channel and lateral bars.

3) Blockage classification: Jams are classified, using the scheme developed by Gregory et al. (1985), according to their potential to block the downstream movement of water and sediment. The classification types are:

Active: Jam forms a complete barrier to water and sediment movement and also creates a distinct step or fall in the channel profile.

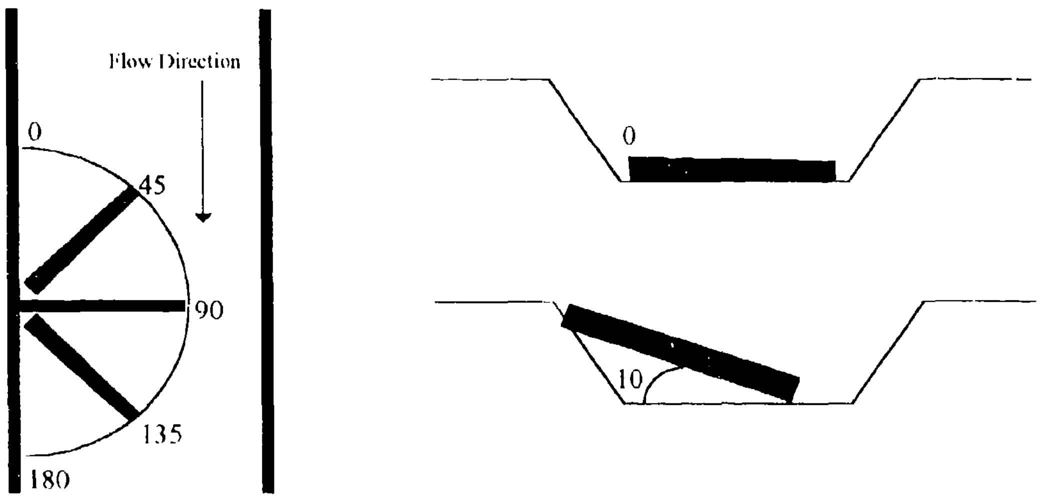
Complete: complete barrier to water/sediment movement, but no significant step.

Partial: Jam is only a partial barrier to flow.

4) Alpha/ Beta Indices: The alpha angle describes the predominant alignment of the debris in the channel with respect to the flow direction. These indices were first used by Cherry and Beschta (1986) in connection with LWD flume experiments. The Beta angle is a measure of the predominant orientation of the debris jam material in the vertical plane, at ninety degrees to the flow direction. See figure 3.1 below.

Figure 3.1 Alpha and Beta Indices (modified from Cherry and Beschta, 1986)

Alpha Index (degrees) **Beta Index (degrees)**



5) Sinuosity : A visual estimate of channel sinuosity in the jam reach (straight, slightly sinuous, sinuous, meandering).

6) Knickzones : Presence of Kickpoints or knickzones in the channel reach (a measure of channel instability).

7) Sediment : Bedload D_{50} classification (clay, silt, sand, gravel)

8) Deposition/Scour : Estimated volume of bar deposition, backwater sedimentation and bed/bank scour induced by each jam. Total deposition and scour values are then calculated for each channel reach.

The debris volume and debris frequency measures, morphological classification, jam sedimentation and erosion, and net jam sediment bubgets in each reach have been and plotted against three independant catchment variables. These are; reach drainage basin area, average reach channel width; and reach average unit stream power. Unit stream power is calculated using the following equation:

$$\omega = \frac{\rho g Q s}{w} \tag{3.1}$$

where: ω = stream power per unit bed area N/m/s

ρ = density of water kg/m^3

g = gravitational constant (9.81 m/s/s)

Q = predicted Q_2 discharge (cumecs)

s = bed slope (m/m)

w = reach average channel width (m)

These independent catchment variables are used to determine whether the geomorphological effects of LWD have a coherent and predictable spatial relationship.

Figure 3.2 Geological map of Mississippi showing the DEC survey area (modified from Watson et al., 1993)

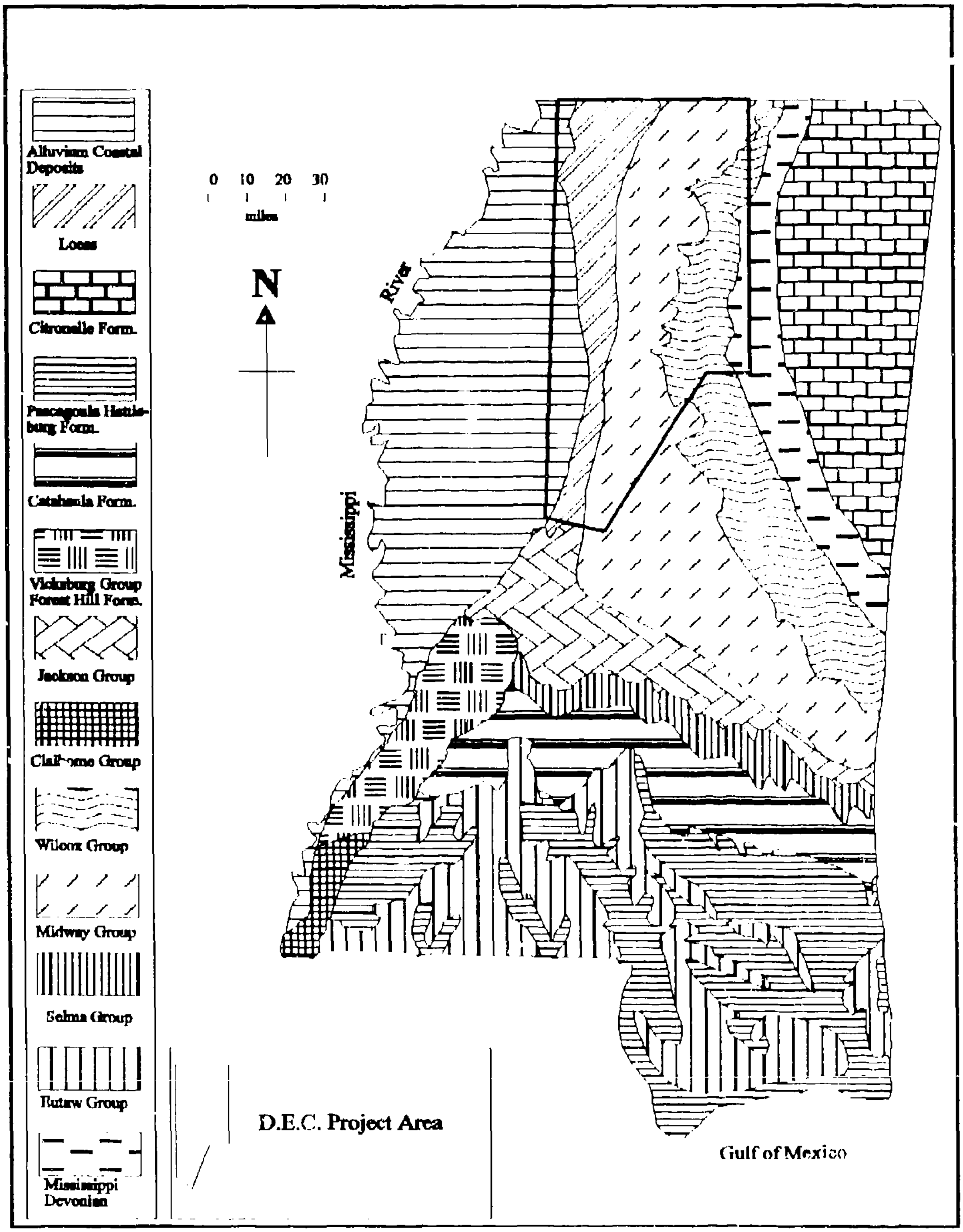
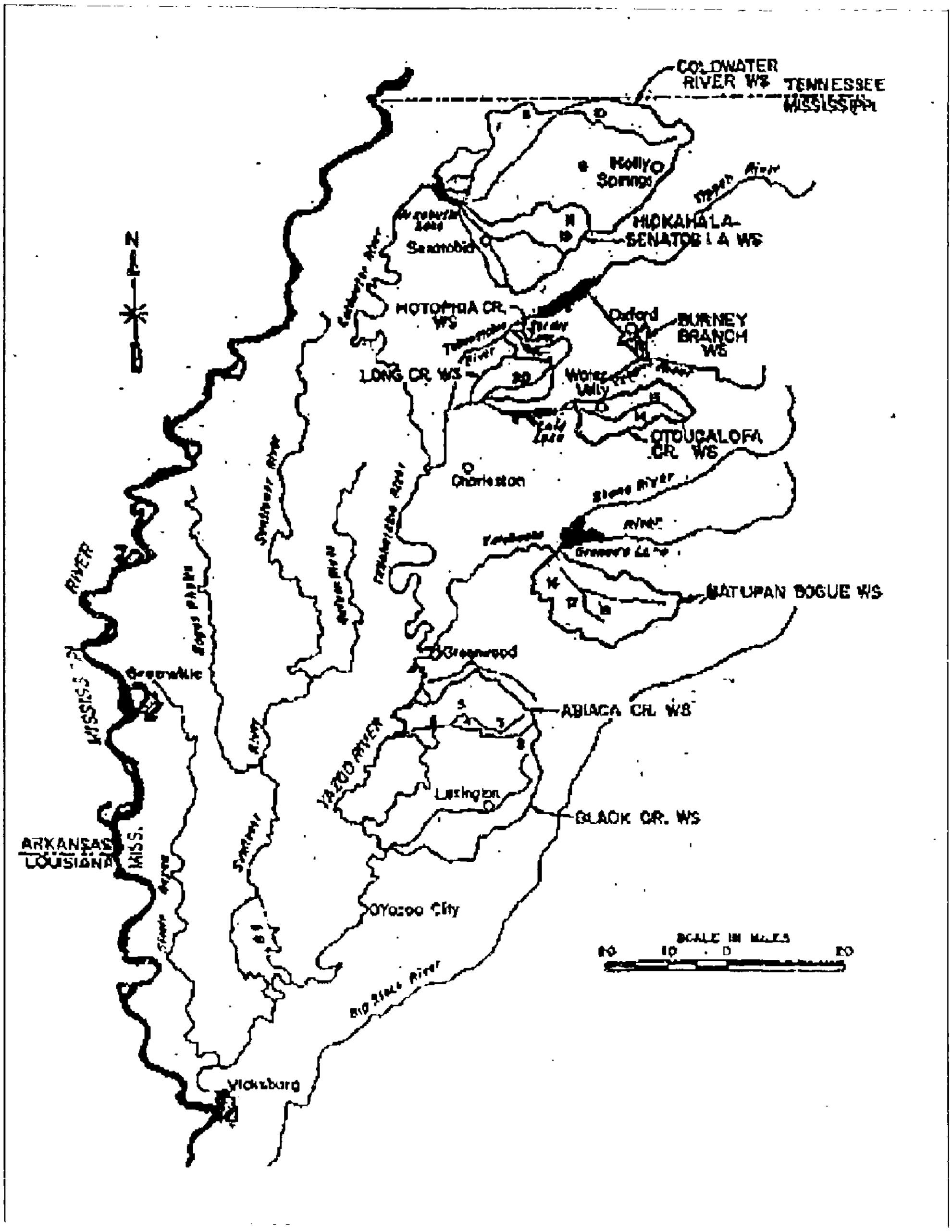


Figure 3.3 DEC project area site location map (modified from Raphelt et al., 1995)



4 RESULTS

Results are divided into analysis of debris input Mechanisms, Processes, and Debris jam residence times.

4.1 INPUT MECHANISMS

Figure 4.1 shows a table of debris input mechanisms at each jam site for each reach which have significant debris jams. The dominant input mechanism is through outer bank erosion in active meanders (43%), followed by input due to reach scale instability (30%). Random input processes (windthrow, beaver activity and floated material) accounted for only 37% of debris input in total. Debris input in these unstable rivers is therefore, in general, caused by spatially predictable phenomena. Debris input zones and major dam accumulation can thus be located, without resorting to expensive and time consuming field reconnaissance, by using secondary map data to locate channel reaches which have wooded riparian zones with active meandering and/or lateral instability due to degradation. In catchments up to about 50 miles square jams appear to form where the key debris (that is large whole trees which initiate jam formation) fall into the channel. Jams are therefore commonly located in bend apices or in unstable reaches downstream of knickpoints. Figure 4.2 demonstrates this observation, showing debris jam locations just downstream of bend apices on a planform plot of Abiaca Creek. Jams do not, however, appear to have a regular or predictable spatial distribution relating to channel bed topography, such as a location on riffle heads.

4.2 IMPACTS UPON CHANNEL MORPHOLOGY

4.2.1 Impact upon bed topography

Comparison of thalweg plots from reaches which are located in wooded riparian zones with those which are located in agricultural riparian zones show that bed topography is generally much more varied in wooded reaches. The difference in morphology must be due, in the most part, to the presence of debris-induced bed scour and sedimentation because the other controlling variables, including sediment load and substrate geology are identical.

This difference can be illustrated by comparing thalweg plots for Redbanks Creek (figure 4.40), which has a purely agricultural riparian zone, with Worsham Creek, West Fork (figure 4.31) which has a wooded riparian zone.

4.2.2 Debris Jam Reconnaissance analysis

Refer to figure 4.3 showing the geomorphological reconnaissance results for the May 1995 survey.

The following geomorphological variables have analysed and plotted against three independent catchment variables; drainage basin area, stream power and channel top width; to determine whether the geomorphological effects of LWD have a coherent and predictable spatial relationship.

1) Number of Jams per unit reach length

Figure 4.4 shows a plot of the number of debris jams per 1000ft of channel, for each reach surveyed, against drainage basin area. A negative relationship was expected in this plot because of the greater flow competence in channels with a larger catchment, however, no clear function is evident in the plot. Jam frequency has also been plotted against reach average composite channel top width, and reach unit stream power. These are graphed in figures 4.5 and 4.6. Again, however, no relationship, positive or negative is evident in either plot. A simple spatial relationship is therefore too simple an approach to understanding debris jam dynamics and it must be recognised that debris jam frequency (and therefore volume) in particular reaches is also heavily dependant on the comparative rate of debris input processes at work, in balance with transport from the reach. Input rates may vary enormously, especially in the environment in question, where heavy debris input through bank erosion is dependant upon channel instability and active meandering processes, factors which are, to a certain degree, independent of the reach catchment area.

2) Volume of debris per unit reach length

Figure 4.7 shows a plot of the volume of debris present in each channel per 1000ft equivalent against drainage area. A negative trend in this plot might have been expected because more debris is likely to be mobilised in larger catchments due to greater flow competence and the increasing channel dimensions as compared to the average key debris size. There is no significant trend evident, however, the plot being almost horizontal, with the exception of one or two reaches, most notably Abiaca 6 (drainage area 99 mi^2). It is possible that, rather than debris volume being a smooth function of drainage area, a step in the debris transport capacity exists due to some threshold discharge value for transport of the key in-channel debris. Although a step exists between the volume in Abiaca 6 and the other reaches in smaller catchments, there is insufficient data over the full range of drainage area displayed to demonstrate such a phenomena conclusively. Plots of debris volume against composite channel width (figure 4.8) and stream power per unit channel width (figure 4.9) also show no significant directional trend, again where negative relationship may have reasonably been expected.

3) Flow deflection classification

Figure 4.10 shows a bar chart of jam morphological classification plotted against drainage basin area classes with a 10 mi^2 interval. Unfortunately, because there are not an equal number of observations in each category it is very difficult to make a meaningful interpretation of the different distributions in each category. If, however, the categories containing debris jams are taken as representational of all the jams present over that range, the distribution shows a weak trend from dam type jams in catchments less than 10 mi^2 through to a dominance of parallel jams in larger catchments (> 40 mi^2).

4) Flow blockage classification

The influence that each jam has, in terms of blocking flow and sediment movement is qualitatively described using the Active/Complete/ Partial classification (see chapter 3). Partial jams make up 82% of the total, complete jams 14% and active jams only 4% (see figure 4.3). The majority of jams are therefore partial and do not cause significant backwater effects and backwater sediment wedge formation. Log steps, which are a major feature associated with debris jams in gravel bed rivers (see Macdonald, 1982) are therefore not a prevalent feature in these unstable, sand-bed creeks.

5) Alpha angle

The Alpha variable describes the mean angle of orientation of debris relative to the channel flow direction. There is no distinct relationship with increasing drainage basin area (no plot shown), although it could be theorised that the alpha angle would increase from 90 to 180 degrees as drainage area (and therefore channel width and mean discharge) becomes larger due to greater flow forces in larger channels causing the rotation of trees parallel with the current. The results in figure 4.3 show that fifty eight percent of the sites have a mean debris direction of 90 degrees, 24 percent have a mean direction of 180 degrees, and 18 percent have a mean direction between 90 and 180 degrees. It is evident therefore that the majority of trees enter the channel at 90 degrees to the flow, some are subsequently rotated by the force of flow, but these observations demonstrate that the tree length/channel width index, which has been used to describe blockage, and flow disturbance, by debris, is quite justified for modelling purposes (see Wallerstein 1995).

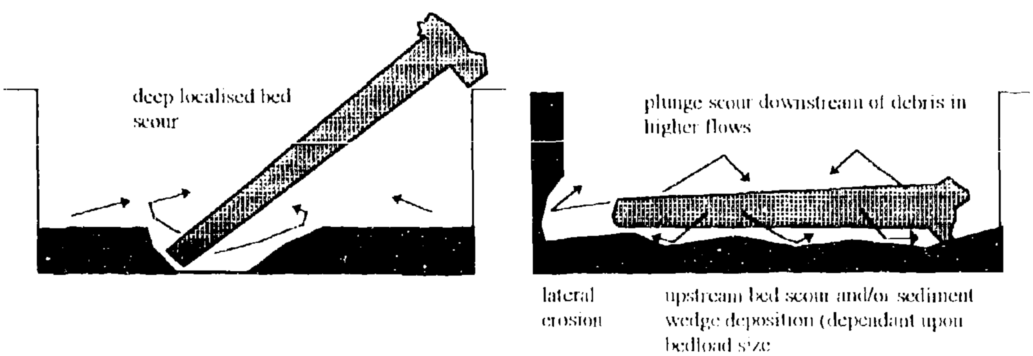
6) Beta angle

The Beta variable describes the mean angle of debris in relation to the channel bed. Debris that rests on the channel bed along its entire length has a value of 0 degrees, while debris which has one end in the channel and the other end supported on the bank has a Beta value ranging between 0 and 90 degrees. Referring to figure 4.3, data show that eighty five percent of debris jams have an average beta angle of 0 degrees, while only 15 percent have a beta angle greater than 5 degrees. Thus, at the majority of sites debris will offer maximum blockage area at low flows, helping to retain sediment transported in the flow, but at the same time causing flow constriction and deflection which may result in bank failure. Debris inclined more than 5 degrees appears to be more prevalent at creeks which have a low width to depth ratio, such as Nolehoe creek where the w/d ratio approaches 1 in certain sections, the obvious reason for this relationship being that trees falling into these channels will rotate more than 90 degree before coming to rest (unless they span the channel).

Debris Beta angle will affect the morphological impact that a jam has upon the channel. Steeply inclined debris is unlikely to cause significant flow deflection and will have a low sediment retention capacity as compared with debris lying parallel to the channel bed. Significant bank erosion or bar formation is therefore unlikely, however, localised scour around the debris will cause pools to form akin to those caused by flow round bridge piers. Debris lying on the channel bed along its full length will have greater interaction with the flow and a range of features may develop depending upon the sediment type, and stage of flow. Such debris inclination also offers at greater upstream area on which to trap floating debris, and these jams will consequently grow, and become more coherent structures, at a faster rate than inclined debris formations. See figure 4.11

Figure 4.11 : Flow patterns around debris with different inclinations

Beta Angle 20 degrees   Beta Angle 0 degrees

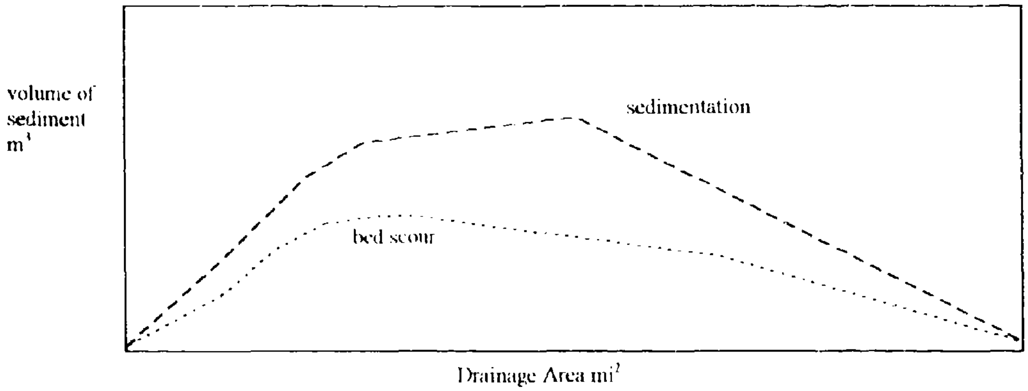


7) Sedimentation and scour associated with debris jams

Sedimentation and scour values for each site are shown in figure 4.3. These values have been graphed in figure 4.12 against drainage basin area, against unit channel width in figure 4.13, and against stream power per unit width in figure 4.14. Triangles represent sediment retention, through backwater and bar deposits, for each creek, averaged over 1000 ft. Rectangles represent bed scour due to flow restriction and turbulence around debris jams for each creek, averaged over 1000 ft of channel. While no distinct pattern emerges in any of the three plots, in figure 4.12 it is evident that sedimentation and scour values are low at sites less than 10 mi^2, then increase to a peak at between 20 and 40 mi^2 and then appear to decline in larger catchments. This trend is also vaguely apparent in figure 4.13 with sedimentation rising to a peak at a channel width of around 58 ft then declining to zero at 108 ft. The peak value for scour in figure 4.12, discounting the extreme value at 24 mi^2, lies at around 19 mi^2 while the peak value for sedimentation lies at around 42 mi^2. This peak distribution is contradicted somewhat in the composite width plot where scour values peak at a larger width than that for sedimentation, however, the general pattern can be explained if it is linked to the idealised debris channel interaction curves outlined in Wallerstein (1994 [illegible] k values for bed scour lie in the zone where underflow and dam-type jams are likely to be prevalent, that is, where flow is constricted and, in the underflow dam case, forced to impinge on the channel bed resulting in the formation of scour holes. Scour values then tail away as flow constriction around debris is reduced as channel widths become greater than the average debris length. Sedimentation values peak at slightly larger drainage areas, where jams are either of the dam or deflector type. Dam type jams will trap sediment in the backwater area, while deflector dams often have a bar downstream of the jam due to energy dissipation and low/mid flow deflection towards the channel bank. In larger channels still, jams become flow parallel and occupy a smaller percentage of the channel cross section, so that sedimentation, through energy dissipation around the debris becomes less effective. The idealised distribution of debris related sedimentation and scour with increasing drainage basin area is shown in figure 4.15 below. It must be recognised that it is often difficult to attribute areas of sedimentation or scour specifically to a debris jam. This is especially the case with areas of bar sedimentation in larger channels, where a circular explanation problem arises in that bars may either be initiated by energy dissipation in the lee of a debris build-up, or may pre-date the debris, which subsequently comes to rest upon its upstream face. This problem was recognised by Hickin

(1984) when trying to explain the formation of scroll-bars. In either case, however, debris would, at the very least, enhance sediment deposition on the bar.

Figure 4.15 : Idealised diagram of debris related sedimentation and scour



The magnitude of the scour and sedimentation peaks may well vary with bedload and suspended sediment type, with coarse, gravel, loads causing the sedimentation peak to rise, and the bed scour peak to fall proportionately, and vice-versa with a fine sand or silt sediment load.

The LWD sediment budget for each reach surveyed (averaged over 1000 ft. of channel), that is, the difference between the total sedimentation volume and total scour volume, induced by debris, for each channel reach is plotted against drainage basin area in figure 4.16 against composite channel width in figure 4.17 and against stream power per unit channel width in figure 4.18. Relation to the three independent catchment variables reveals no recognisable spatial trends. However, quite importantly, the graphs do show that the balance between sediment scour, and sediment deposition caused by debris jams is in favour of net sedimentation, with nine of the channel reaches having a positive budget and only four having a negative budget. The total difference between positive and negative budgets, summed together for all channel reaches leaves a net positive balance of 98 m^3 of sediment. This value would be much higher if it were not for the one anomalous negative budget value of -260 m^3. This value relates to Harland Creek (reach 1) and is thought to be partly due to overestimation of debris related scour in channel bends where it was hard to distinguish between meander pools and scour induced by flow constriction around debris. The net positive sediment balance lends weight to the argument that debris has an overall beneficial impact, in terms of sediment retention in these highly unstable channels with excessive sediment yields, although the total retention values are possibly negligibly small when compared with total sediment yields from each reach.

4.3 DEBRIS JAM RESIDENCE TIMES

Figure 4.19 to 4.40 show thalweg plots for each reach with surveyed positions of each debris jam site marked on. Data from the May 1995 survey are overlaid onto the May 1994 plots so that an assessment can be made of the rate of debris input and of the longevity of jams, which determines their effectiveness as geomorphological channel controls.

Initially, it was hoped that consecutive years of bed survey data could be overlaid to monitor changes in topography around each jam site. Unfortunately, however, it has been found that there are too many data survey errors to allow a realistic comparison of local scale features between the two years of data.

Thalweg plots are not available for Coila Creek, Abiaca Creek (site 3) and Hickahala Creek (site 22) due to severe errors in the data.

The following creeks have debris jam sites surveyed into the long profile data :

Worsham Creek (West Fork)	Harland Creek (1)	Hickahala Creek (11)
Worsham Creek (Middle Fork)	Lick Creek	Nolehoe Creek
Sykes Creek	Fannegusha Creek	Abiaca Creek (6)
Lee Creek	Long Creek	Perry Creek

Of these the following reaches has jam sites surveyed in both May 1994 and May 1995:

Harland Creek	Hickahala Creek	Lick Creek
Nolehoe Creek	Abiaca Creek (4)	

The above plots give an indication of the stability of jams and the rate of debris input over the one year period.

Harland Creek (1) : Figure 4.19

Two major jams (1 and 2) surveyed in 1994 were still intact in 1995. In addition, six new jam sites were located, all of which were caused by tree topple due to bank instability.

Hickahala Creek : Figure 4.26

Site 1 had been removed by 1995 due to the construction of a new road bridge. Site 2, a jam formed from branches brought down in an ice storm, had been washed down to jam 3 by may 1995. Site 4 remained intact in 1995 and had collected a large quantity of fresh material.

Lick Creek : Figure 4.21

Site 1 remained intact between 1994 and 1995. Five new underflow type jams with trunks resting across the channel at bankfull level were surveyed in 1995. Many of these are unlikely to interfere with the flow except in the most extreme flood events. Sites 2, 3 and 4 had been removed by May 1995 due to the constr ion of a new high drop grade control structure.

Nolehoe Creek : Figure 4.22

All nine sites surveyed in 1994 were found to be intact in 1995. Several had gained new material both floated down from upstream and from tree topple due to flow deflection and bank undercutting around the existing jams. This reach is highly unstable which accounts for the very large volume of debris present.

Abiaca Creek (site no. 4) : Figure 4.23

Sites 1 and 2, surveyed in 1994 were found to be intact in 1995. These jams have been formed through key debris input where the outer bank of two active meanders have eroded.

It is evident from the comparison of this one year interval data that the majority of jams have remained intact over this period, while a number of new jams have formed. New jams appear to have been initiated either though bank failure in unstable reaches, such as on Harland Creek or through a combination tree blow down on unstable, over steepend banks, such as on the upper reaches of Lick Creek.

Conclusions about short-term jam stability can only be made when the survey data is compared with corresponding discharge data for the one year interval. This will show the magnitude and frequency of events that the jams are able to survive. Unfortunately, as yet the relevant data has not been made available to permit this analysis. Given the warm, humid climate, and highly erodible nature of these channels it is likely, however, that jams are more transient features in northern Mississippi than in Pacific North West gravel bed rivers because debris will decompose quickly and become bypassed and transported downstream more readily. A long-term monitoring programme is required, however, to verify this assertion

New debris jam sites were surveyed at six creek reaches. It is not known if these jams were present in May 1994 because time constraints meant that debris reconnaissance could not be carried out at these reaches.

Sykes Creek : Figure 4.24

Four sites were surveyed into this reach. Key debris input is primarily the result of outer bank failure in active meanders.

Fannegusha Creek : Figure 4.25

This reach is highly unstable and has just had a grade control constructed at it's downstream end. Three major debris jams were located within the reach, all cause by bank failure input.

Abiaca Creek (site 6) : Figure 4.26

This reach is situated at the point where the creek flows out of the Bluff Line hills onto the Mississippi floodplain. The gradient is shallow and the channel is agrading slightly. The two jams present appeared to have been formed by material that has floated down from upstream rather than from local tree input.

Lee Creek : Figure 4.27

Four small jams were found in this reach. Two in the upstream section have been created by debris input due to bank instability, while the two lower down the reach appear to have been formed by blown down trees

Long Creek : Figure 4.28

This entire reach is choked with debris, and "palaeodebris", that is woody material that must have been preserved and buried in the alluvium of older channels, and is now being exhumed by the creek as it erodes into it's bed and banks. Distinct jams are very hard to define in this reach, but nine concentrations of debris were surveyed into the thalweg data. This reach was highly unstable in the past but is now beginning to stabilise due to the construction of a major grade control at the downstream end of the reach, and several smaller structures, upstream through the reach section.

Perry Creek : Figure 4.29

This reach displays all the phases of the channel evolution sequence (see Schumm, Harvey and Watson, 1984), from type 5 at the lower limit of the site to undisturbed type 1 at the upstream end. Seven jam sites were located in this reach. Two jams in the lower reach have been created by blown down trees, three in the upper third of the reach are located in unstable, type 2, channel and have resulted from bank instability, and the final two jams, located in type 1 channel, in the upstream end of the reach, have been created by bend outer bank erosion.

The following two reaches had jams surveyed in May 1994 but were not survey in May 1995 owing to time constraints:

Worsham Creek (Middle Fork) : Figure 4.30

Thirteen sites were surveyed into this reach. Debris input had occurred mainly through bank failure, and the entire reach appeared to be degrading and laterally unstable.

Worsham Creek (West Fork) : Figure 4.31

Seven sites were surveyed into this reach. Sites four and five were beaver dams, while the other jams were created by debris input through, slab type, bank failures.

The remaining reaches (figures 4.32 to 4.40) have no debris jams surveyed into the thalweg plots. Otoucalofa Creek (figure 4.33), James Wolf Creek (figure 4.34), Sarter Creek (figure 4.36), Abiaca Creek, site 21 (figure 4.37), Burney Branch (figure 4.38), Harland Creek, site 23 (figure 4.39) and Red Banks Creek (figure 4.40) were all surveyed for debris but were found to contain no jams. The reason for an absence of debris material was found to be due to three factors. Either, one, because the reach is stable and has no major bank erosion (Sarter Creek, Burney Branch and Abiaca Creek, site 21), two, because the reach has no woody riparian zone to supply material to the channel (James Wolf Creek and Red Banks Creek), or, three, because the discharge, and channel dimensions of the creek are such that even large whole trees which fall into the creek do not remain in one location long enough to establish a coherent jam before being swept away downstream (Otoucalofa Creek, Harland Creek, site 23, and Abiaca Creek, site 21).

Worsham Creek, East Fork (figure 4.32) and Hotopha Creek (figure 4.35) have not been surveyed for debris jams, but it is suspected that debris is present in these reaches owing to the fact that both are known to be degrading and may well therefore have unstable, failing, banks.

Figure 4.1 LWD Input Mechanisms (May 1995 Survey)

creek	site	Input mechanism at jam: death	beaver activity	windthrow	channel instability	active meandering	floated from upstream
Abiaca 3	1				o		
	2					o	
	3					o	
	4					o	
	5					o	
	6					o	
Fannegusha	1						o
	2				o		
	3				o		
Harland 1	1				o		
	2				o		
	3						o
	4					o	
	5					o	
	6					o	
	7				o		
	8					o	
Abiaca 4	1						o
	2					o	
Otoucalofa	debris on outside of most bends - failed and floated						
Lee	1			o			
	2			o			
	3			o			
Nolehoe	1				o		
	2-3				o		
	4-5				o		
	6				o		
	7				o		
	8				o		
Lick	1				o		
Perry	1					o	
	2			o			
	3				o		
	4				o		
	5				o		
	6					o	
	7					o	
Abiaca 6	1						o
	2			o			
Coila	1			o			
	2			o			
	3			o			
	4					o	
	5					o	
	6					o	o
	7					o	o
Sykes	1						o
	2					o	
	3					o	
	4					o	
Worsham W	1				o		
	2					o	
	3			o			
	4				o		
	5		oooo				
	6					o	
	7					o	
	8				o		
	9				o		
Harland 23	1						o
	2				o		
	other					oooooooo	
Long	1				o		
TOTAL		0	4	8	22	31	8
TOTAL %		0	6	10	30	43	11

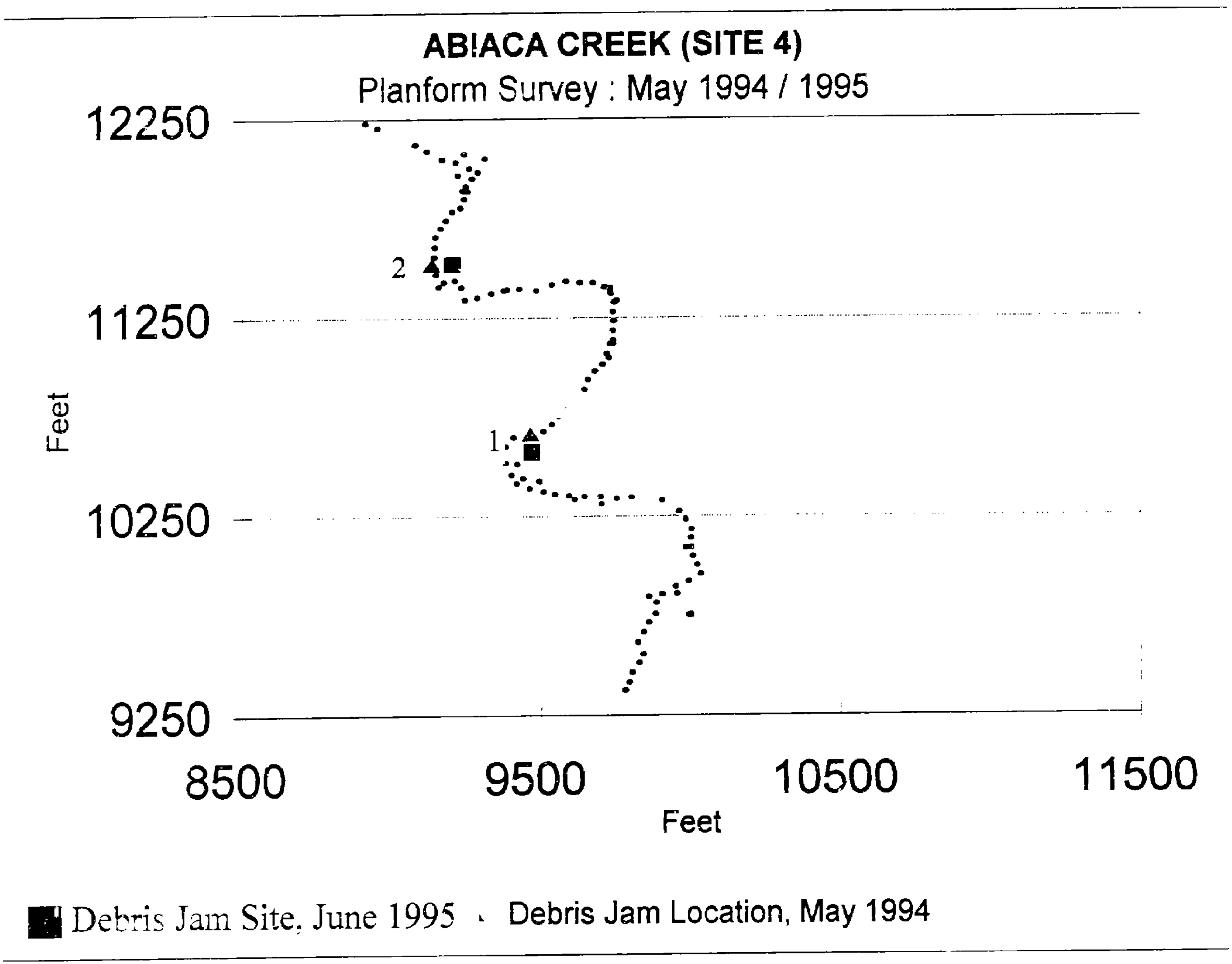


Figure 4.2 Planform plot of Abiaca Creek, Site No. 4

Figure 4.3 LWD Geomorphological Reconnaissance Data (May 1995)

Creek	Site	No. Jams	Vol. jams (m^3)	Flow Direction	Influence	Alpha Angle	Beta Angle	Sinuosity	Knickzone	sediment	Bar deposition (m^3)	Backwater Deposition (m^3)	Bed Scour (m^3)
Abaca 3	1		8 83	dam	partial	90	0	slightly sinuous	no	sand		1x5x0 5	
	2		0 75	dam	partial	100	0	slightly sinuous	no	sand	2x10x0 5		0 5x2x2
	3		6 36	dam	partial	90	0 20	slightly sinuous	no	sand		minor	minor
	4		13 15	dam/deflector	partial	90 130	0	sinuous	no	sand	7x12x2		10x1x1
	5		8 48	deflector	partial	90	10	meandering	no	sand	12x6x0 5	8x10x0 5	8x3x1
	6	6	3 39	dam	active	90	0	meandering	no	sand	point bar	minor	
			Total 40 96										
											Total sedimentation 254 ptf 63 3		Total scour 36 ptf 9
Tennegusha	1		5 65	dam	complete	90	0	straight	no	sand			
	2		31 42	dam-underflow	partial	90	0	straight	yes	sand	10x6x0 5		30x10x1
	3	3	3 14	dam	partial	90	0	straight	yes	sand	10x10x1		
			Total 40 21										
											Total sedimentation 130 ptf 32 5		Total scour 300 ptf 75
Harland 1	1		13 42	deflector	complete	90-180	0	slightly sinuous	no	sand/gravel	10x6x2	20x10x0 5	5x5x1
	2		8 83	parallel	partial	180	0	slightly sinuous	no	sand/gravel	15x5x0 5		20x10x3
	3		8 47	parallel	partial	180	0	meandering	no	sand/gravel	5x10x1		20x10x2
	4		14 12	parallel	complete	90	0	meandering	no	sand/gravel	minor		30x5x3
	5		10 37	parallel	partial	180	0	meandering	no	sand/gravel	25x5x1 5	15x8x0 5	
	6		3 77	parallel	partial	180	0	meandering	no	sand/gravel			40x6x1
	7		9 08	dam	complete	90	0	meandering	no	sand/gravel		10x5x0 5	5x3x1
	8	8	5 29	parallel	partial	180	0	meandering	no	sand/gravel	minor		1x0.5x0 5
			Total 73 35										
											Total sedimentation 580 ptf 128.9		Total scour 1730 ptf 38!
Abiara 4	1		3 45	parallel	partial	180	0 30	meandering	no	sand/gravel			outer bank
	2	2	21 01	deflector-parallel	complete	90 180	0	meandering	no	sand/gravel	10x5x1	20x8x0 5	40x10x0 5
			Total 24.46										
											Total sedimentation 130 ptf 32 5		Total scour 200 ptf 50
Oloualofa	no sites surveyed		Total 27 48										
Long	1	1	19 63	dam-underflow	partial	90	0	meandering	yes	sand			
	rest of reach		127 28										
			Total 146 91								Total 0		Total 0
Lee	1		1 41	deflector	partial	90	0	straight	no	sand	minor		
	2		2 82	dam	partial	90	0	straight	no	sand			
	3	3	1 41	dam-underflow	partial	90	0	straight	no	sand		15x6x0 2	10x5x0 5
			Total 5 64								Total sedimentation 18 ptf 4 5		Total scour 25 ptf 6 25
Hickshala	1		27 29	dam	active	90	0	straight	no	sand/clay bed	15x5x0 5		
	2	2	47 11	dam	complete	90	0	straight	yes	sand/clay bed		15x8x0 5	
			Total 74 4										
											Total sedimentation 97 5 ptf 21 67		Total scour 0
Harland 23	1		12 71	parallel	partial	180	0	meandering	no	sand			
	2	2	15.08	deflector	partial	110	0	meandering	no	sand			
	rest of reach		142 33										
			Total 170 12								Total 0		Total o
Nolehoe	1		5.68	underflow	partial	90-180	30	straight	yes	sand/gravel			
	2 3		22.63	deflector	partial	100	20	straight	yes	sand/gravel/clay		10x6x0.3	10x5x0 5
	4-5		13.2	deflector	partial	130	20	straight	yes	sand/gravel		10x5x0 5	
	6		10.08	underflow	partial	90	20	straight	yes	sand/gravel	15x5x0 5		
	7		16 97	deflector	partial	90-180	20-30	straight	yes	sand/silt/gravel			
	8	8	12 57	deflector	partial	90	10	straight	yes	sand/silt/gravel	0.5x10x5		
			Total 81 09										
											Total sedimentation 105 5 ptf 26 38		Total scour 25 6.25
Lick	1		11 31	deflector	partial	90	0	straight	yes	clay/gravel	15x10x1		minor
			Total 11 31										
											Total sedimentation 180 ptf 45		Total scour 0
Perry	1		2 82	underflow	partial	90	0	sinuous	no	sand			
	2		5 03	underflow	partial	90	0	sinuous	no	sand/gravel			
	3		10 06	dam	complete	180	0	sinuous	no				
	4		7 06	dam	partial	90	0	sinuous	no	sand			
	5		7 06	dam	complete	90-180	0	slightly sinuous	no	sand			
	6		5.03	underflow	partial	90	0	meandering	no	sand			
	7	7	4 24	underflow	partial	90	0	sinuous	no	sand			
	rest of reach		20 27										
			Total 61 57								Total sedimentation 0		Total scour 0
Abaca 6	1	bridge											
	2	2	2 51	parallel	partial	180	0	straight	no	sand/gravel	30x10x0 2		
			Total 2 51										
											Total sedimentation 60 ptf 13 33		Total scour 0
Colle	1		1 41	underflow	partial	90	0	straight	no	sand/gravel	15x4x0 5		
	2		3 93	underflow	partial	90	0	meandering	no	sand/gravel			
	3		1 06	parallel	partial	180	0	slightly sinuous	no	sand/gravel			
	4		4 94	parallel	partial	180	0	slightly sinuous	no	sand/gravel			
	5		5 65	parallel	partial	180	0	meandering	no	sand/gravel	25x10x1		
	6		24 89	parallel	partial	180	0	meandering	no	sand/gravel	point bar		
	7	7	1 57	parallel	partial	180	0	meandering	no	sand/gravel	30x10x1		15x5x1
			Total 43 45										
											Total sedimentation 580 ptf 145		Total scour 65 ptf 16 25
Sykes	1		1 57	deflector	partial	90 180	0	meandering	no	sand	scour at piers		
	2		18 84	deflector	partial	180	0	meandering	no	sand/clay	point bar		
	3		12 57	dam underflow	partial	180	0	meandering	no	sand	10x5x0 5		
	4	4	11 63	parallel	partial	180	0	meandering	no	sand	30x10x1 5		
			Total 44 61										
											Total sedimentation 475 ptf 118 75		Total scour 0
Worsham west	1		5 66	dam underflow	partial	90	5	sinuous	no	sand	10x5x0 3		
	2		0 47	underflow	partial	90	0	sinuous	no	sand			
	3		2 12	dam-underflow	partial	90	0	sinuous	no	sand		10x5x0 5	2x2x0 3
	4		7 54	dam-underflow	partial	90	0	slightly sinuous	no	sand			0 6x3x2
	5		1 96	dam	partial	90	0	slightly sinuous	no	sand			
	6		5 66	dam-underflow	partial	90	0	sinuous	no	sand	5x4x0 5	minor	
	7		6.35	deflector	partial	100	0	sinuous	yes	sand	point bar		2x2x1
	8		12 57	dam-underflow	partial	90	0	slightly sinuous	yes	sand	15x15x0 5		
	9	9	12 57	deflector	complete	90	0	sinuous	yes	sand	8x5x0 5		
			Total 54 9										
											Total sedimentation 182 5 ptf 19 2		Total scour 8 8 ptf 0 93

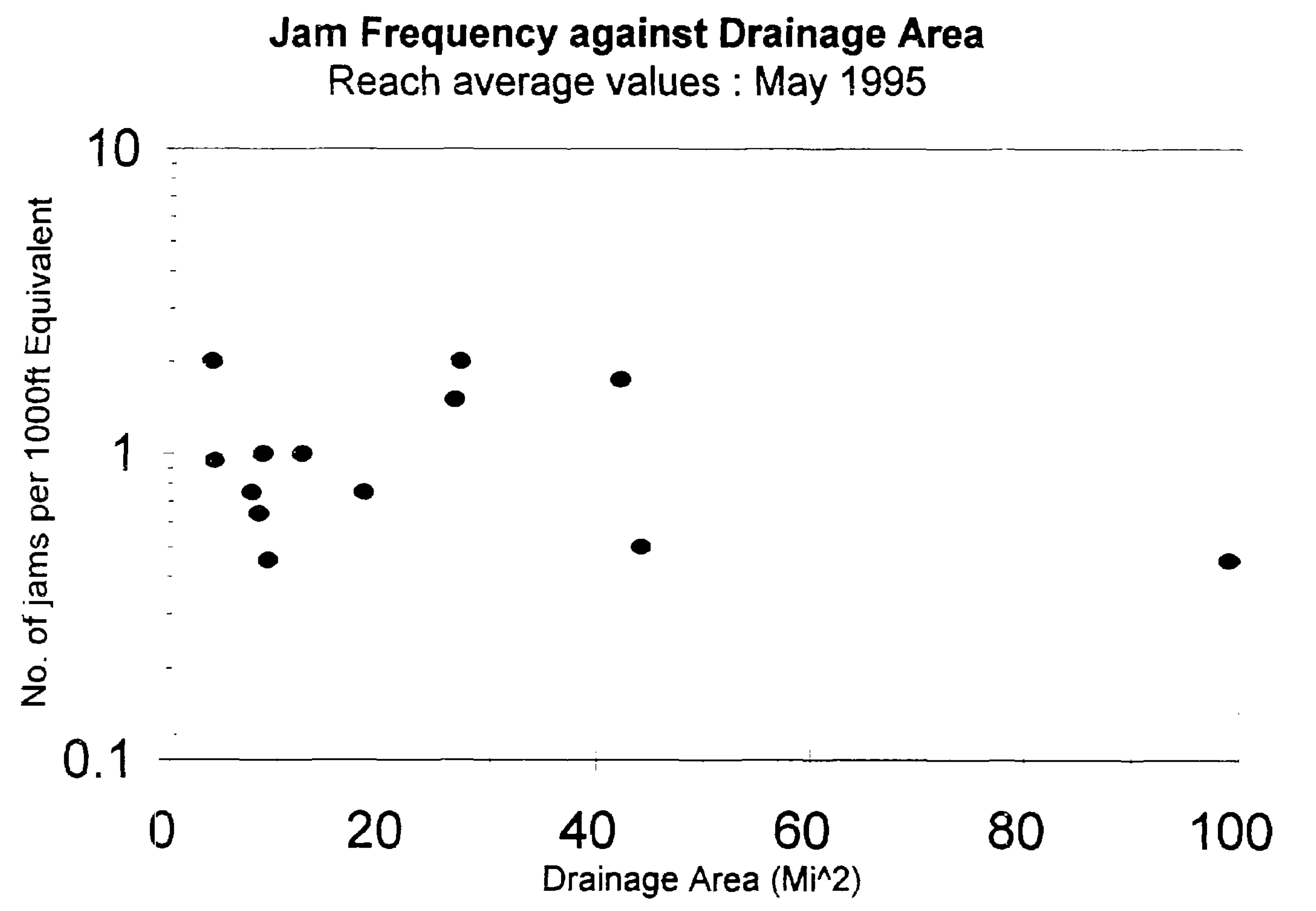


Figure 4.4 Jam frequency against drainage basin area plot

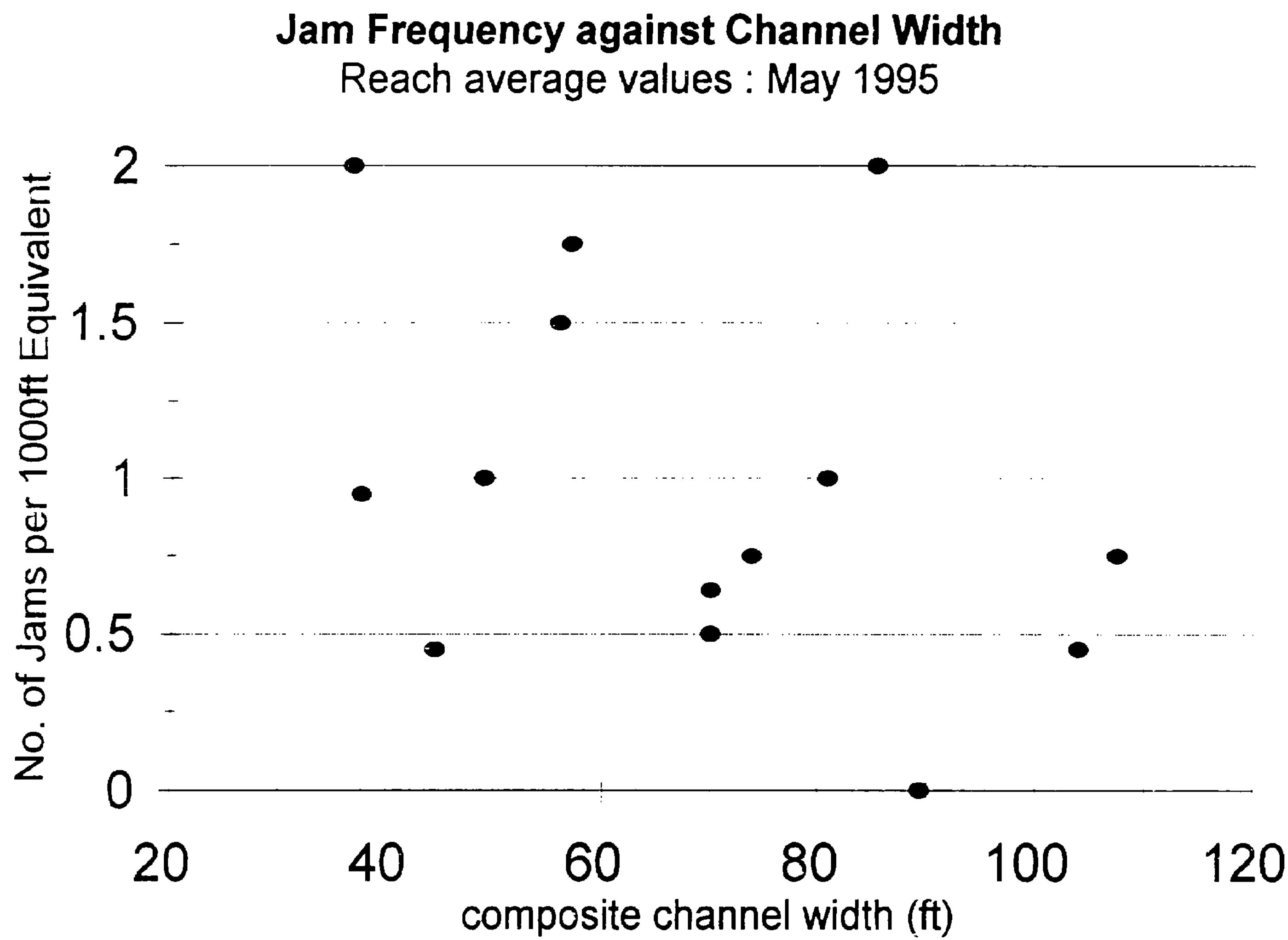


Figure 4.5 Jam frequency against composite channel width plot

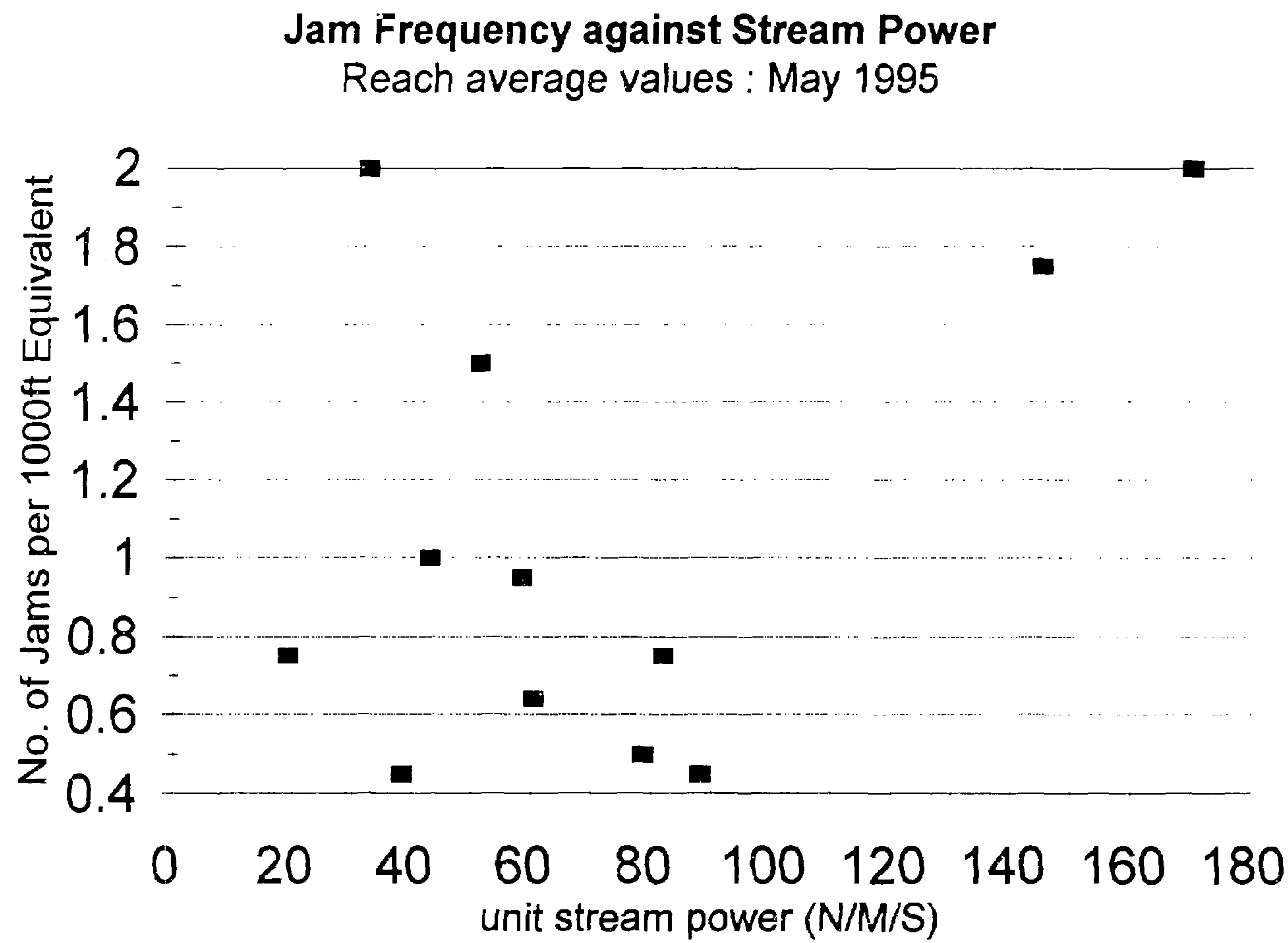


Figure 4.6 Jam frequency against unit stream power plot

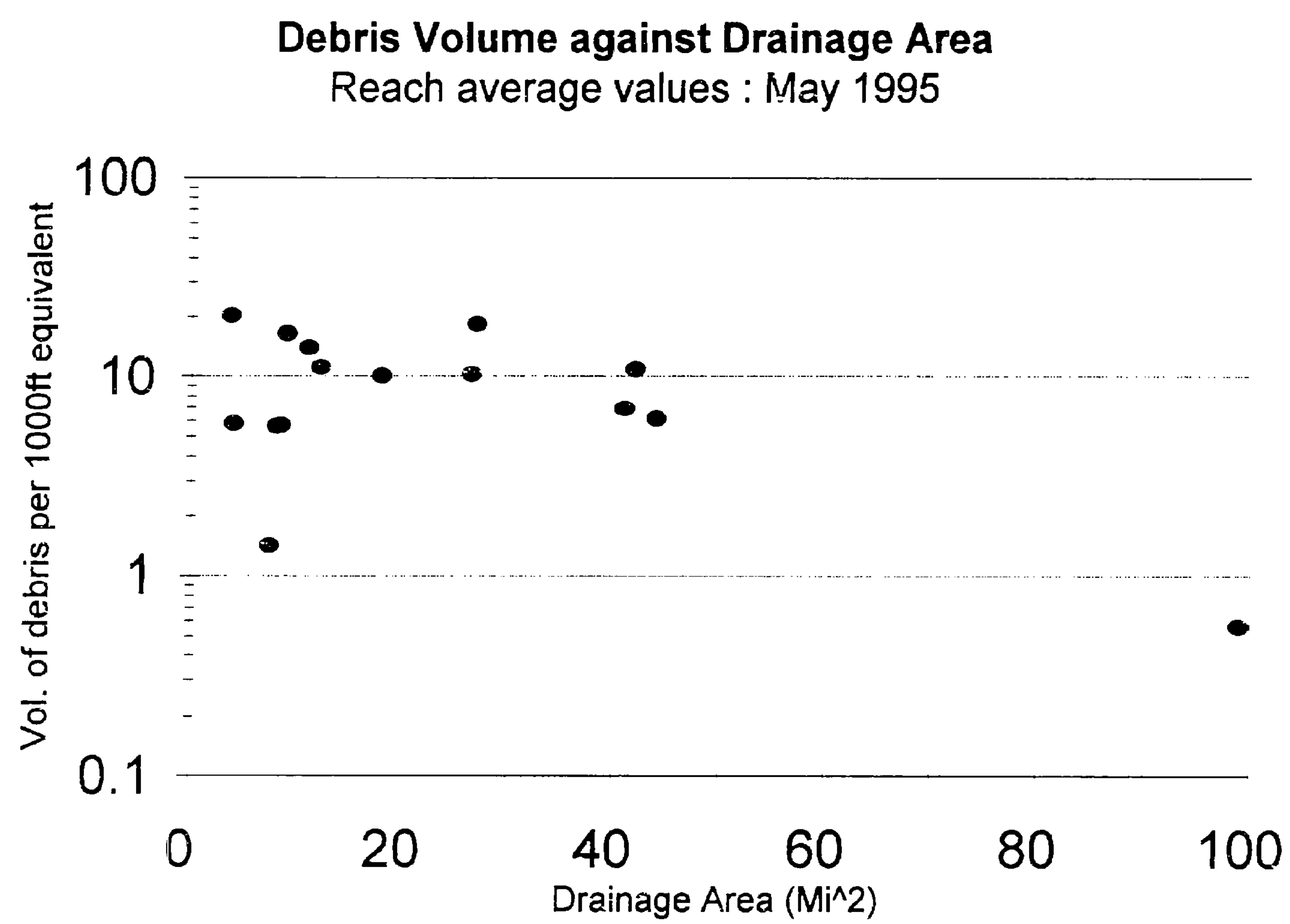


Figure 4.7 Debris volume against drainage basin area plot

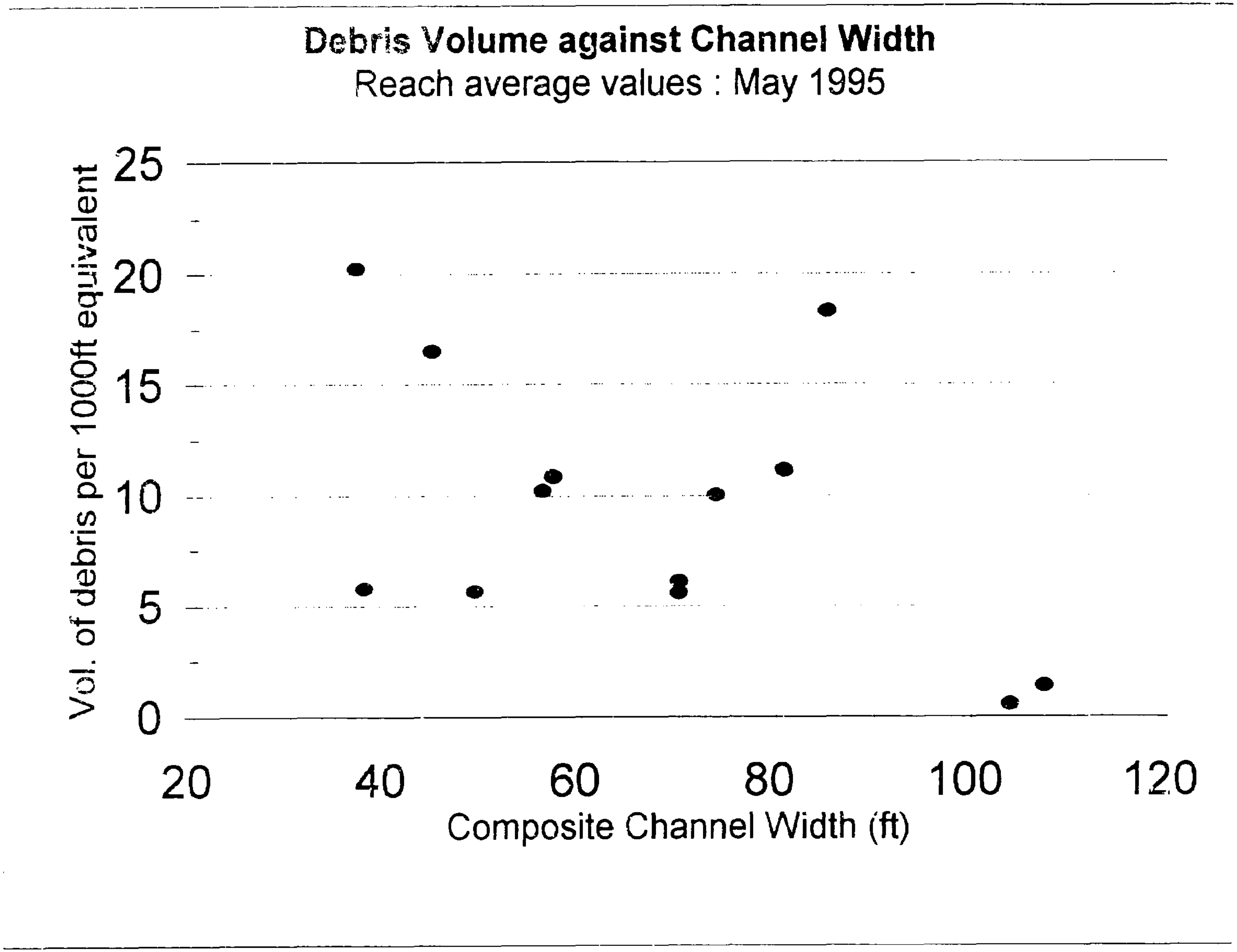


Figure 4.8 Debris volume against composite channel width plot

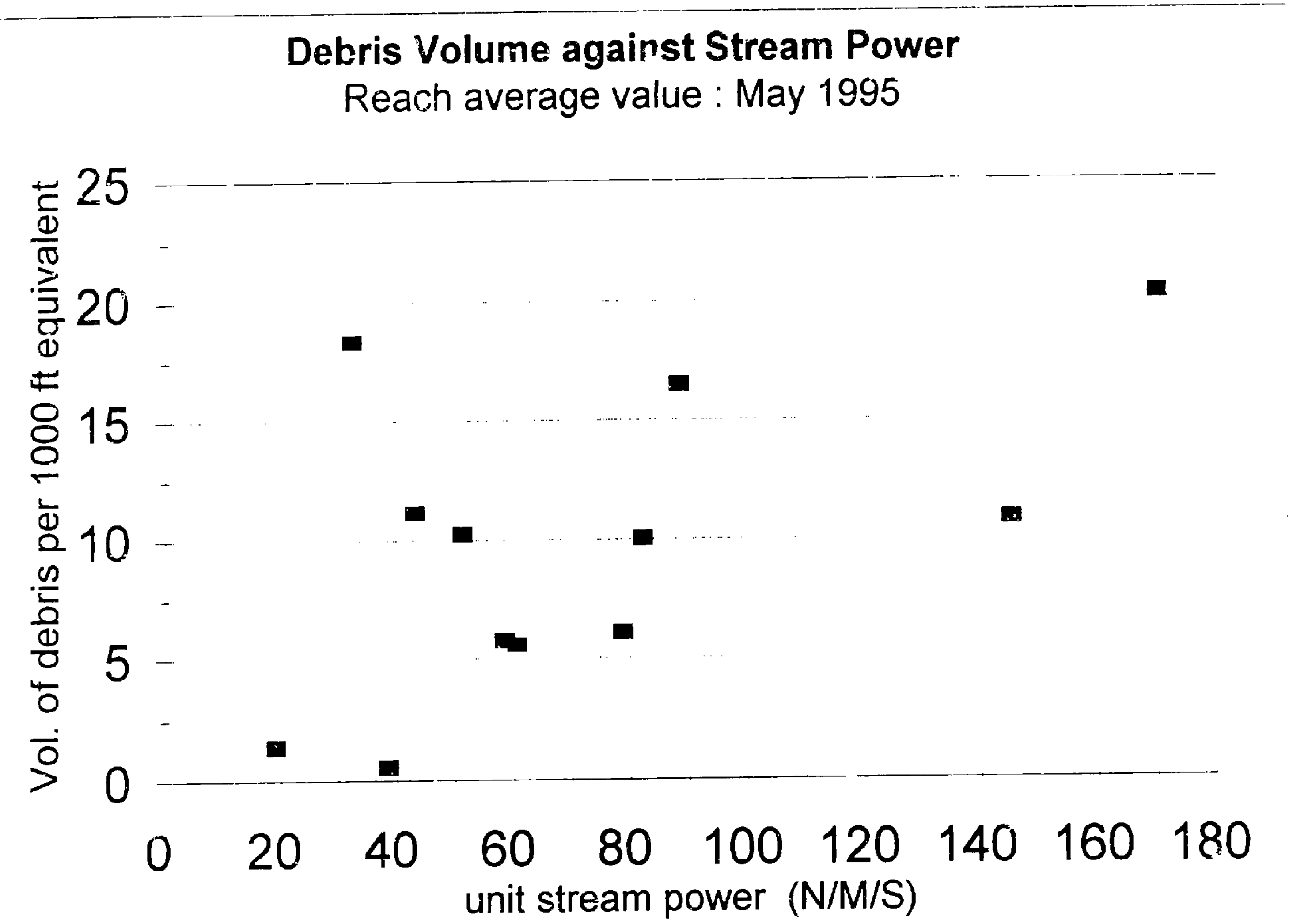


Figure 4.9 Debris volume against unit stream power plot

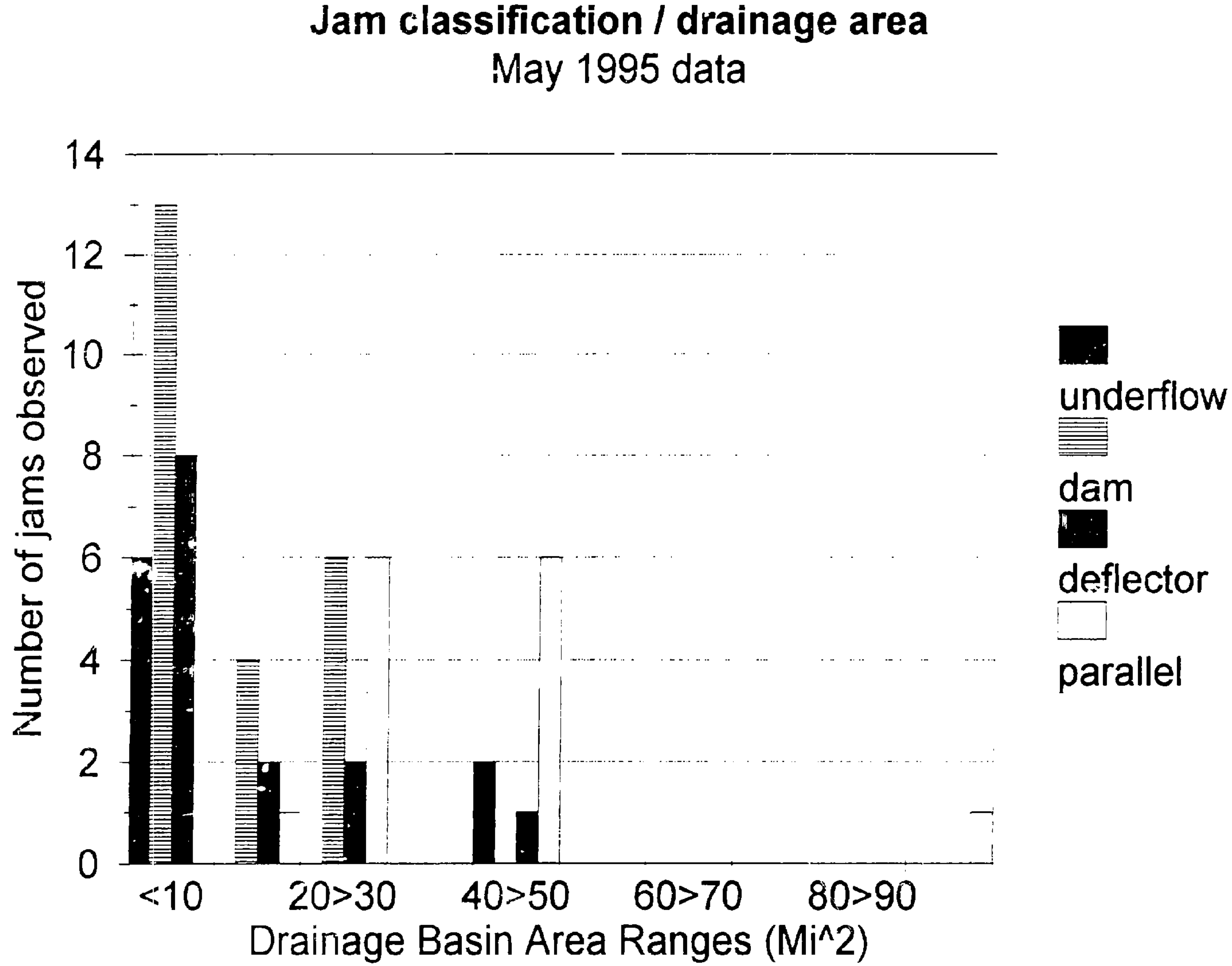


Figure 4.10 Bar chart of jam morphological classification over drainage basin area intervals

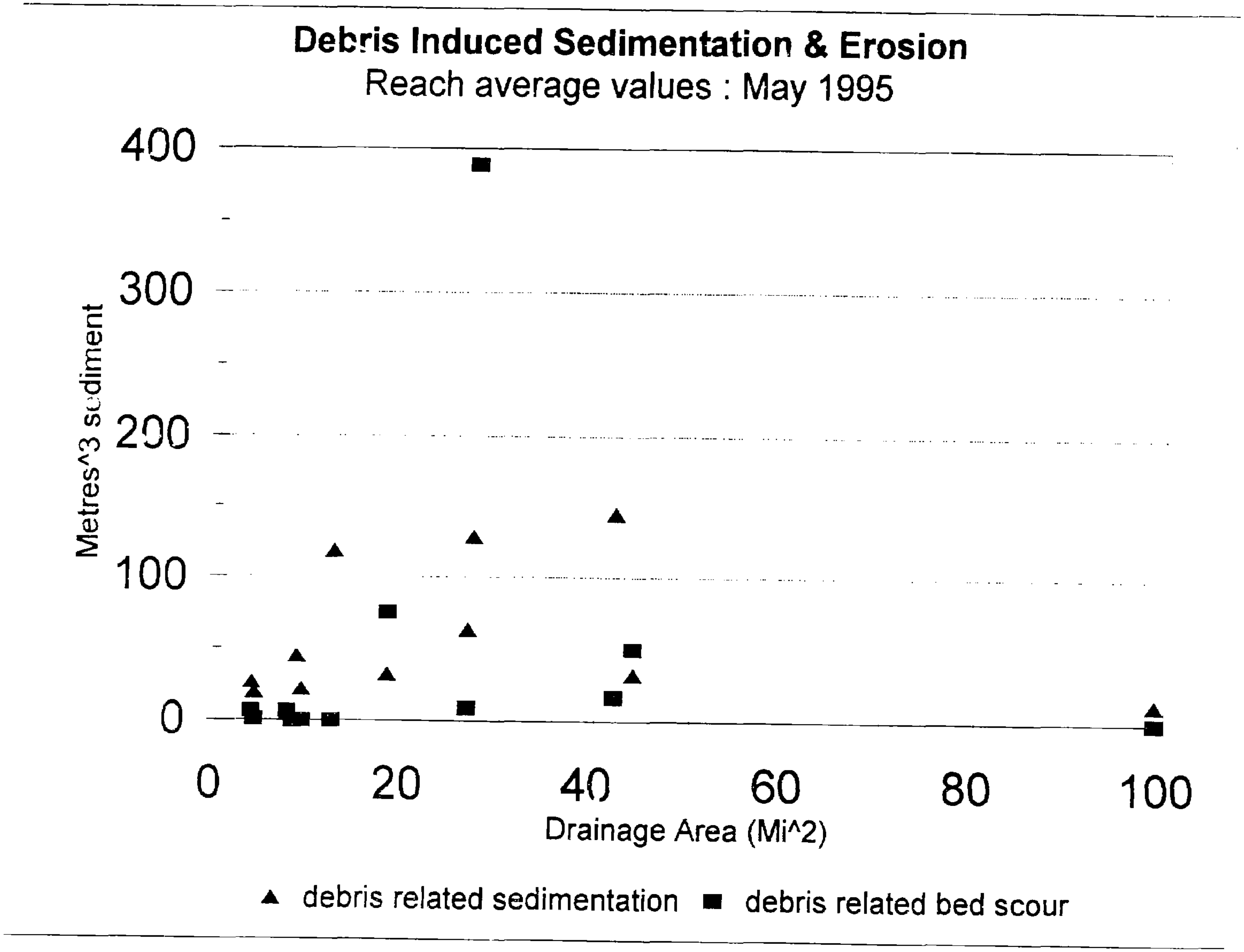


Figure 4.12 Debris induced sedimentation and erosion : drainage basin area plot

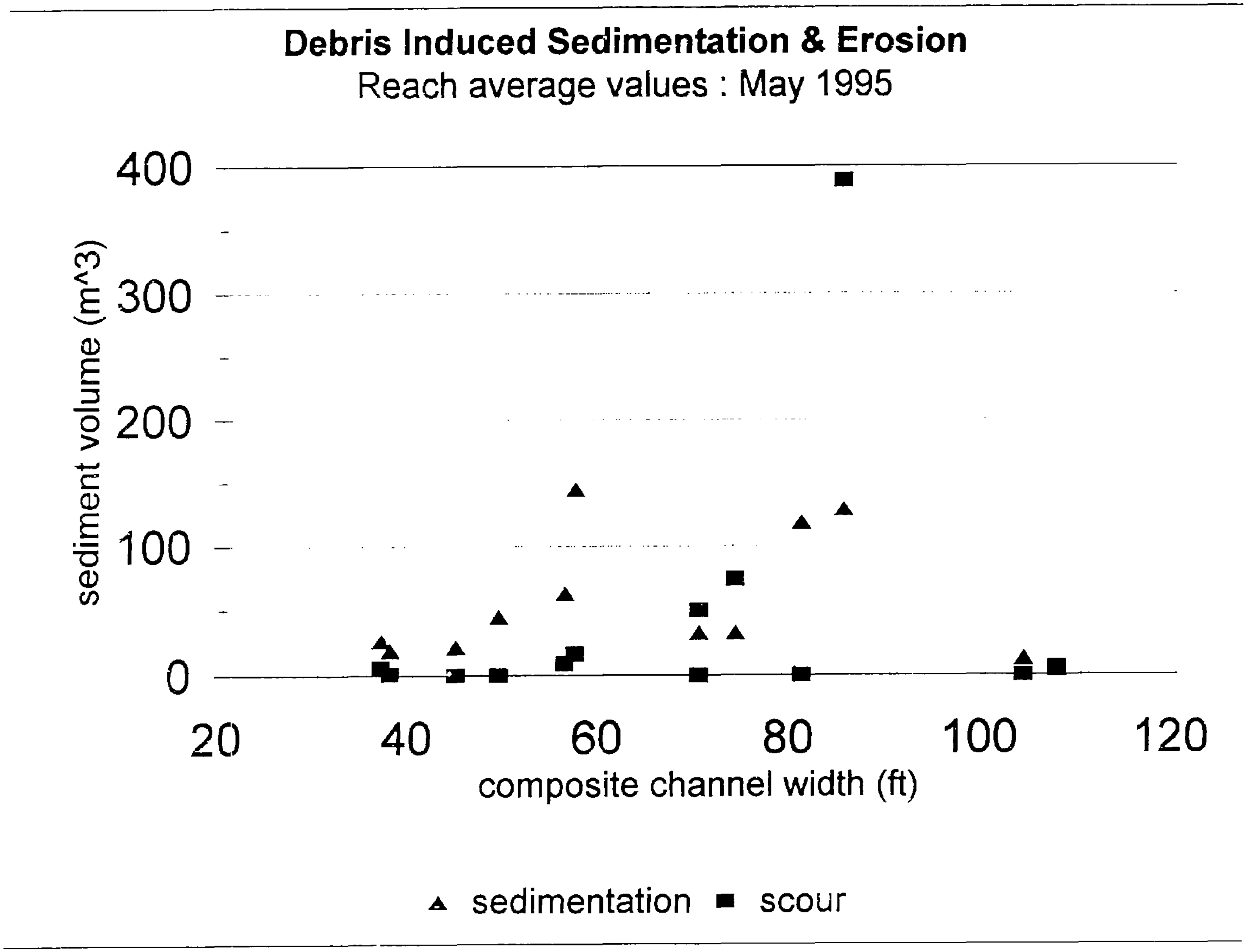


Figure 4.13 Debris induced sedimentation and erosion : composite width plot

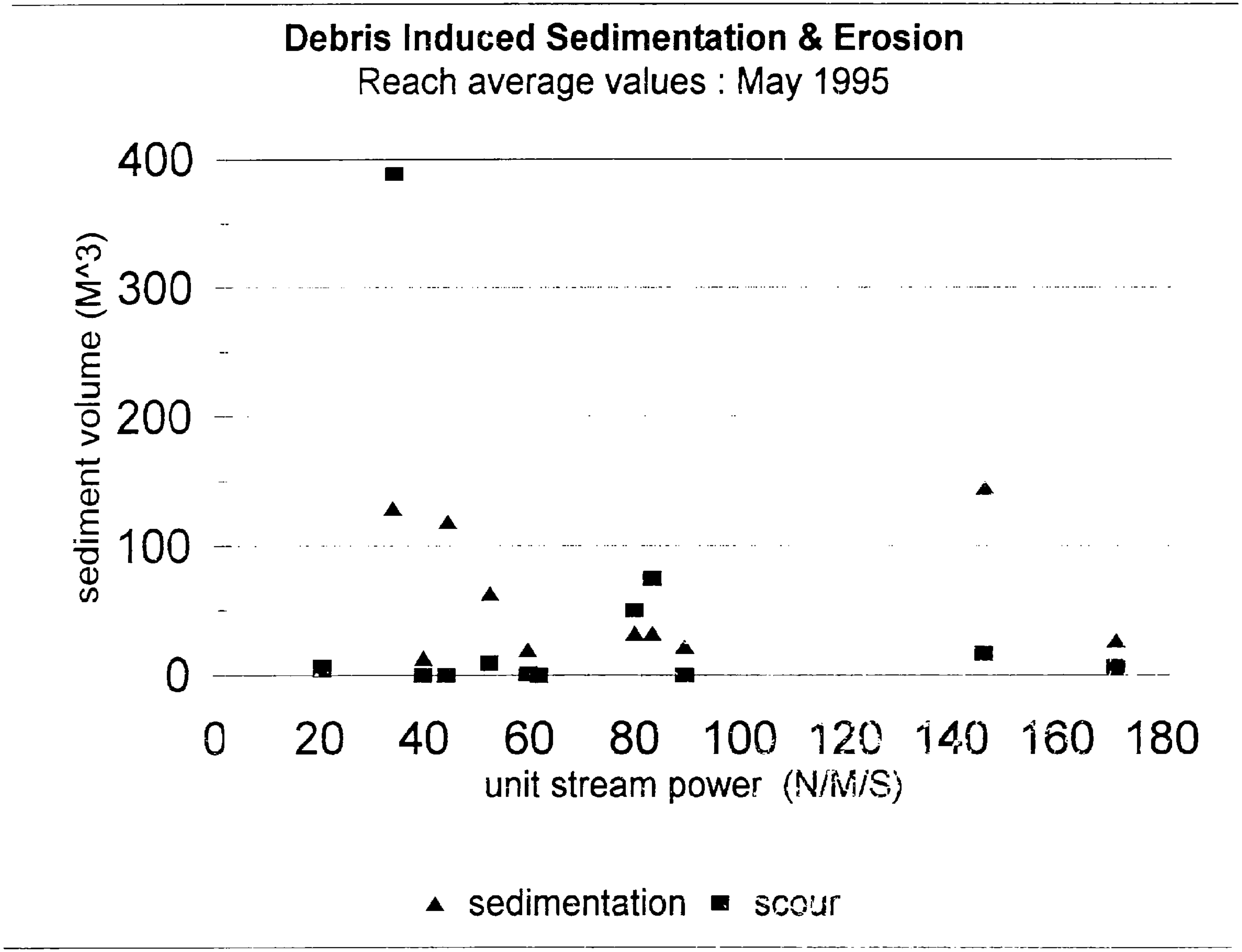


Figure 4.14 Debris induced sedimentation and erosion : unit stream power plot

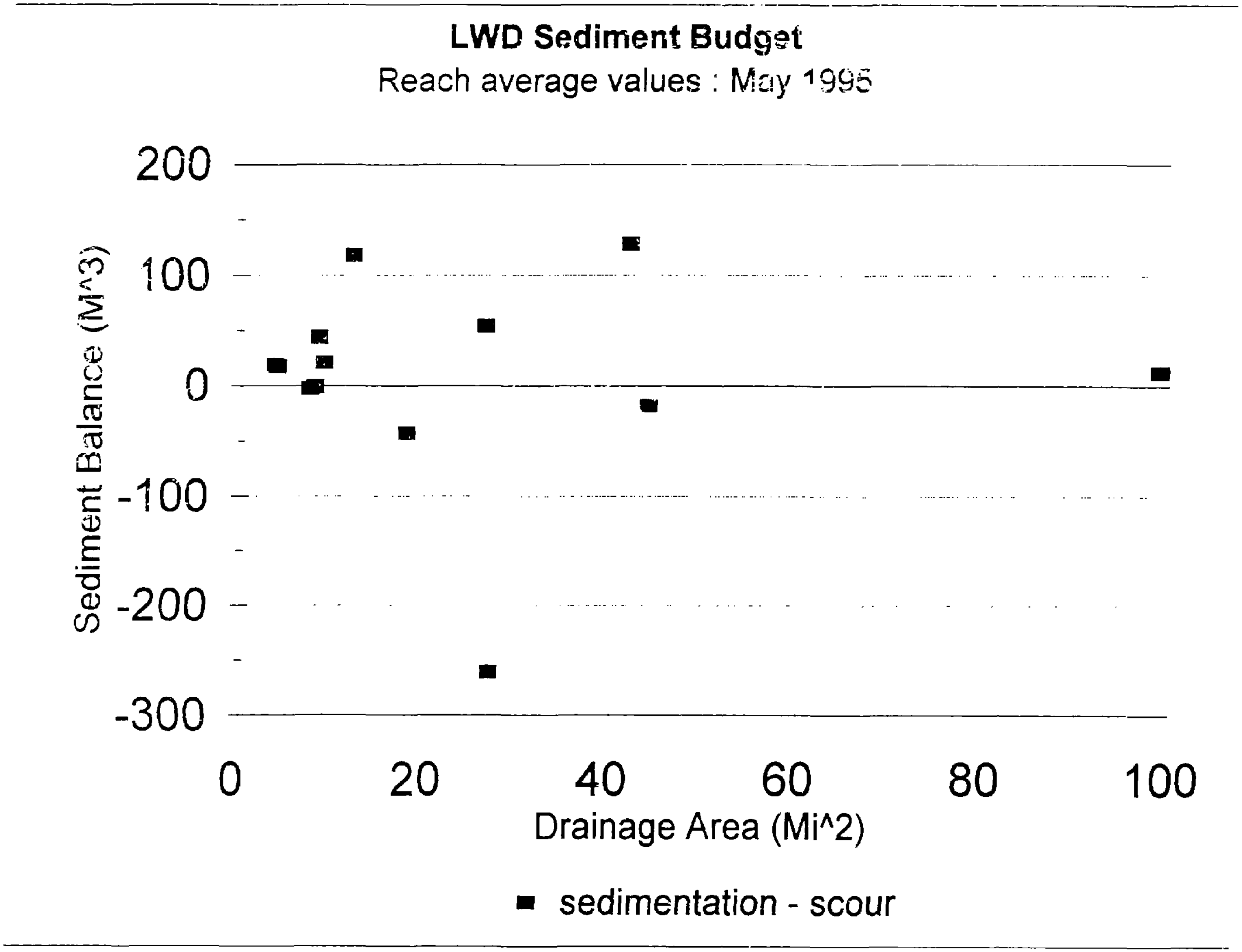


Figure 4.16 LWD sediment budget : drainage basin area plot

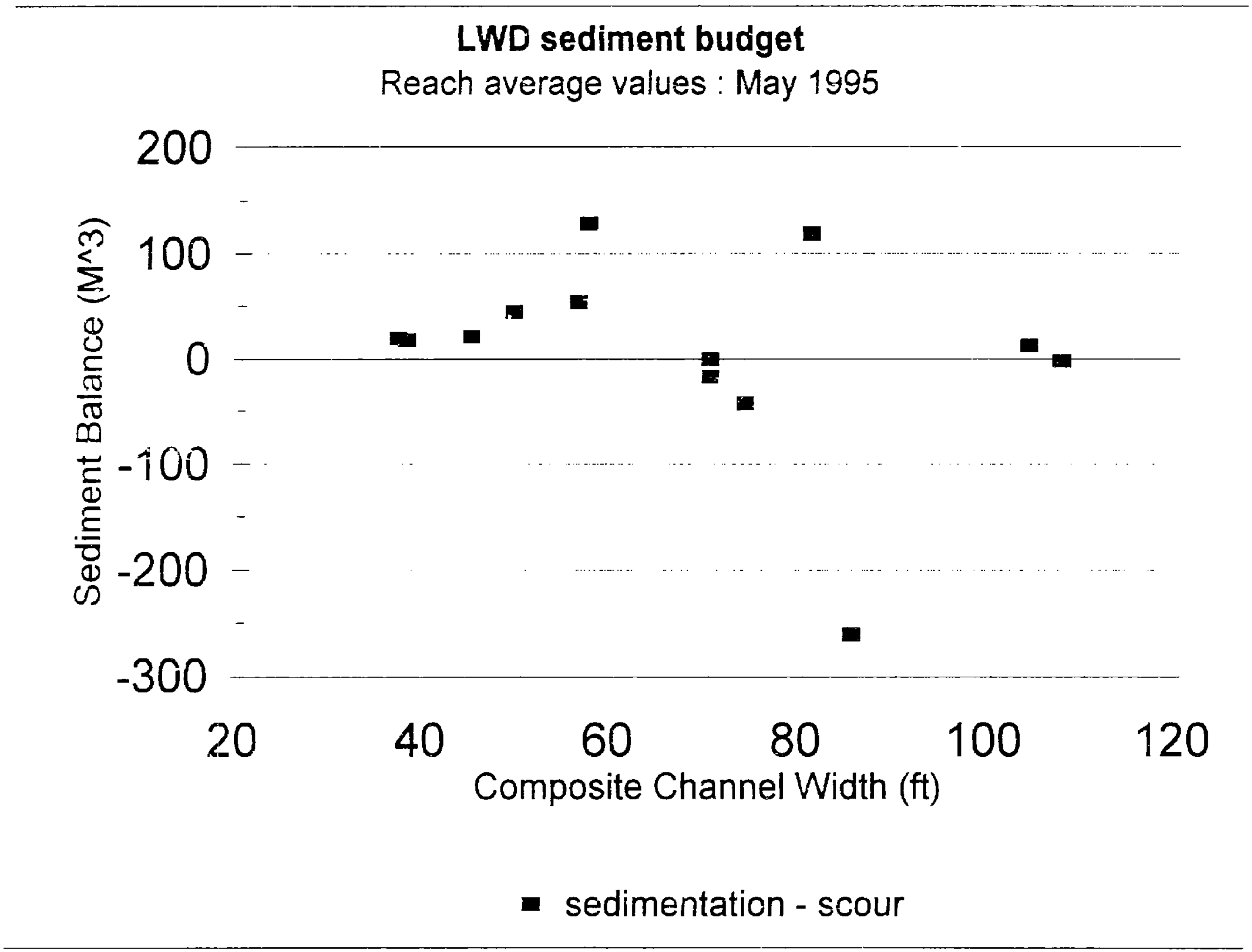


Figure 4.17 LWD sediment budget : composite channel width plot

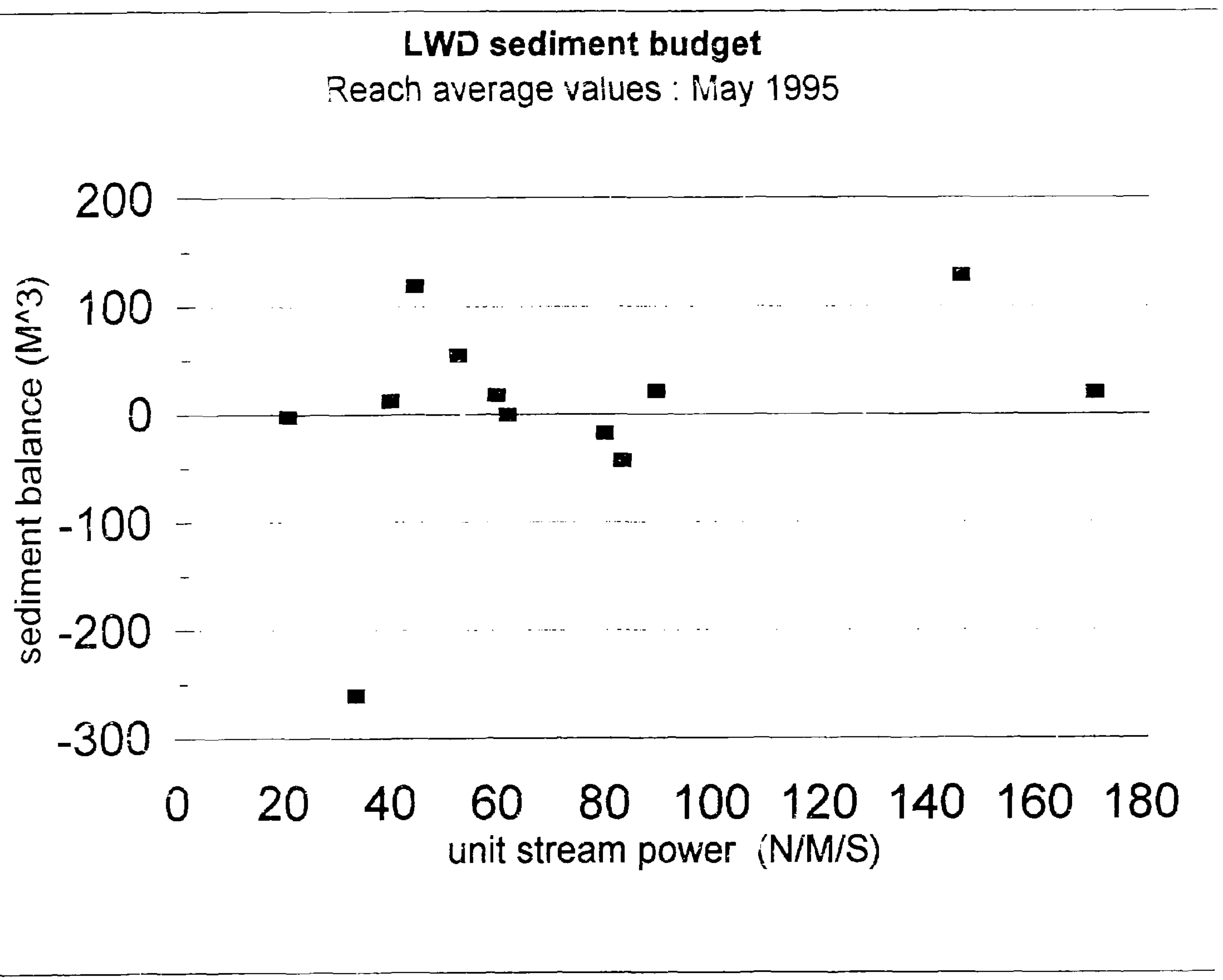


Figure 4.18 LWD sediment budget : unit stream power plot

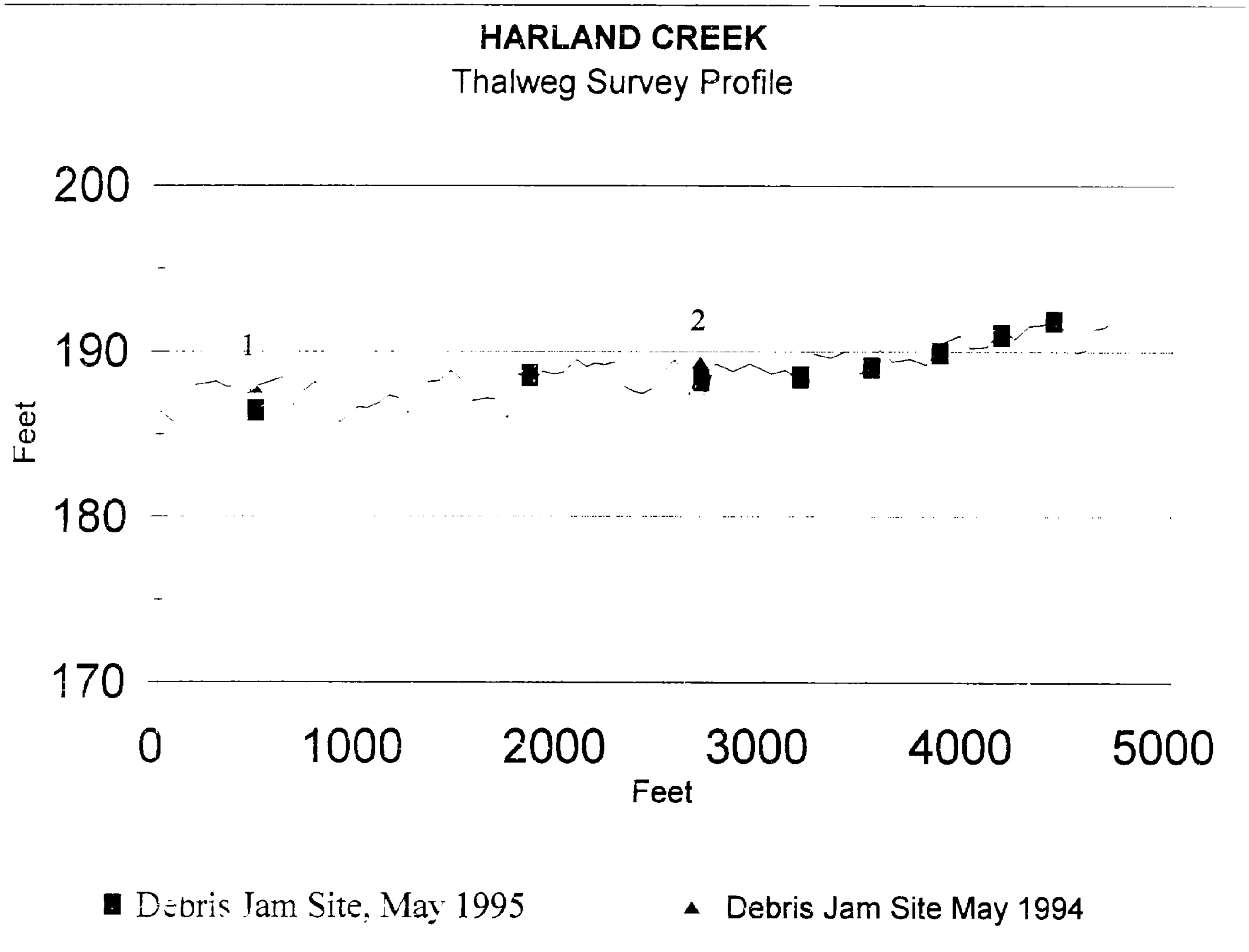


Figure 4.19 Long profile plot of Harland Creek. Site No. 1 : May 1994/95 data.

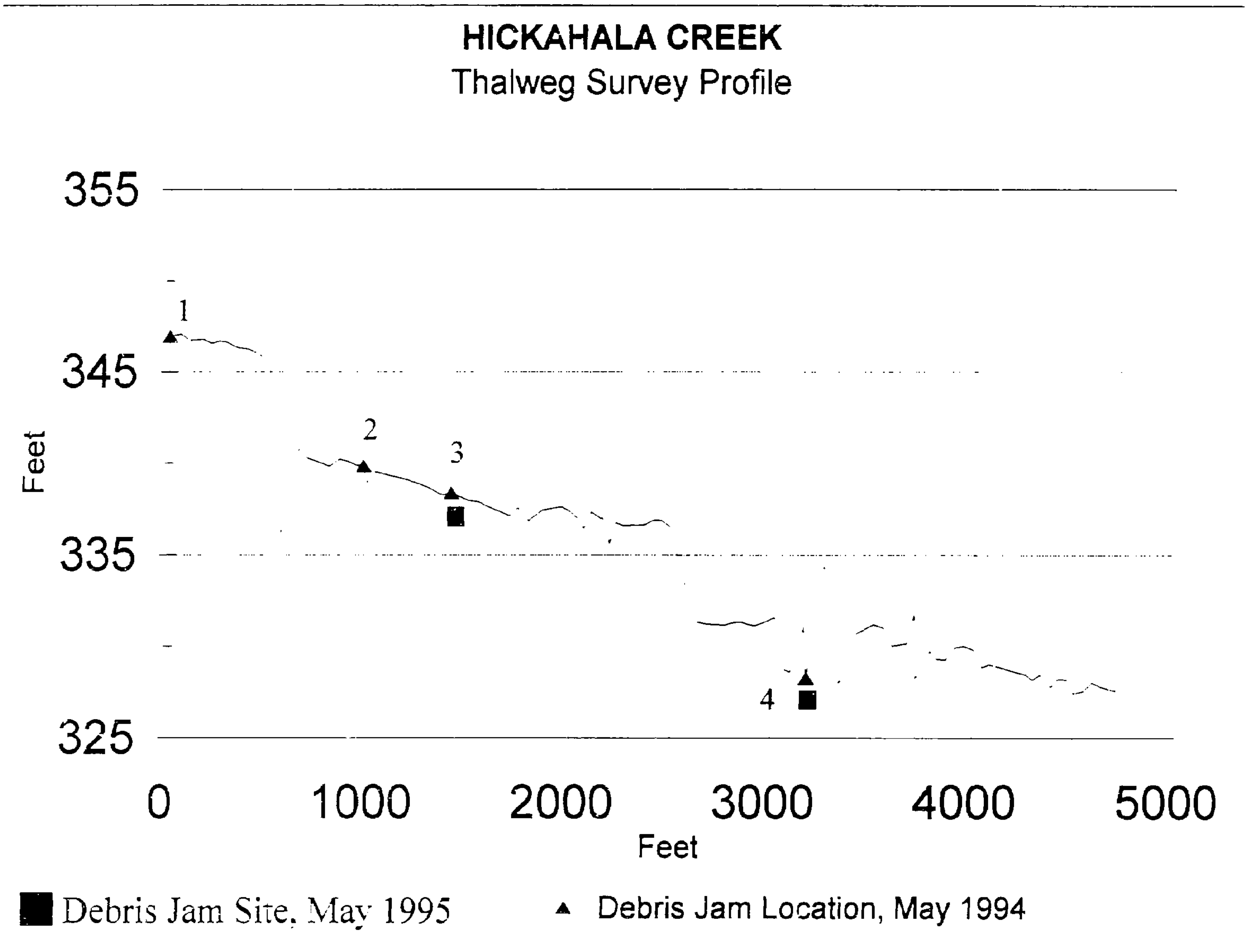


Figure 4.20 Long profile plot of Hickahala Creek, site no. 11 : May 1994/95 data

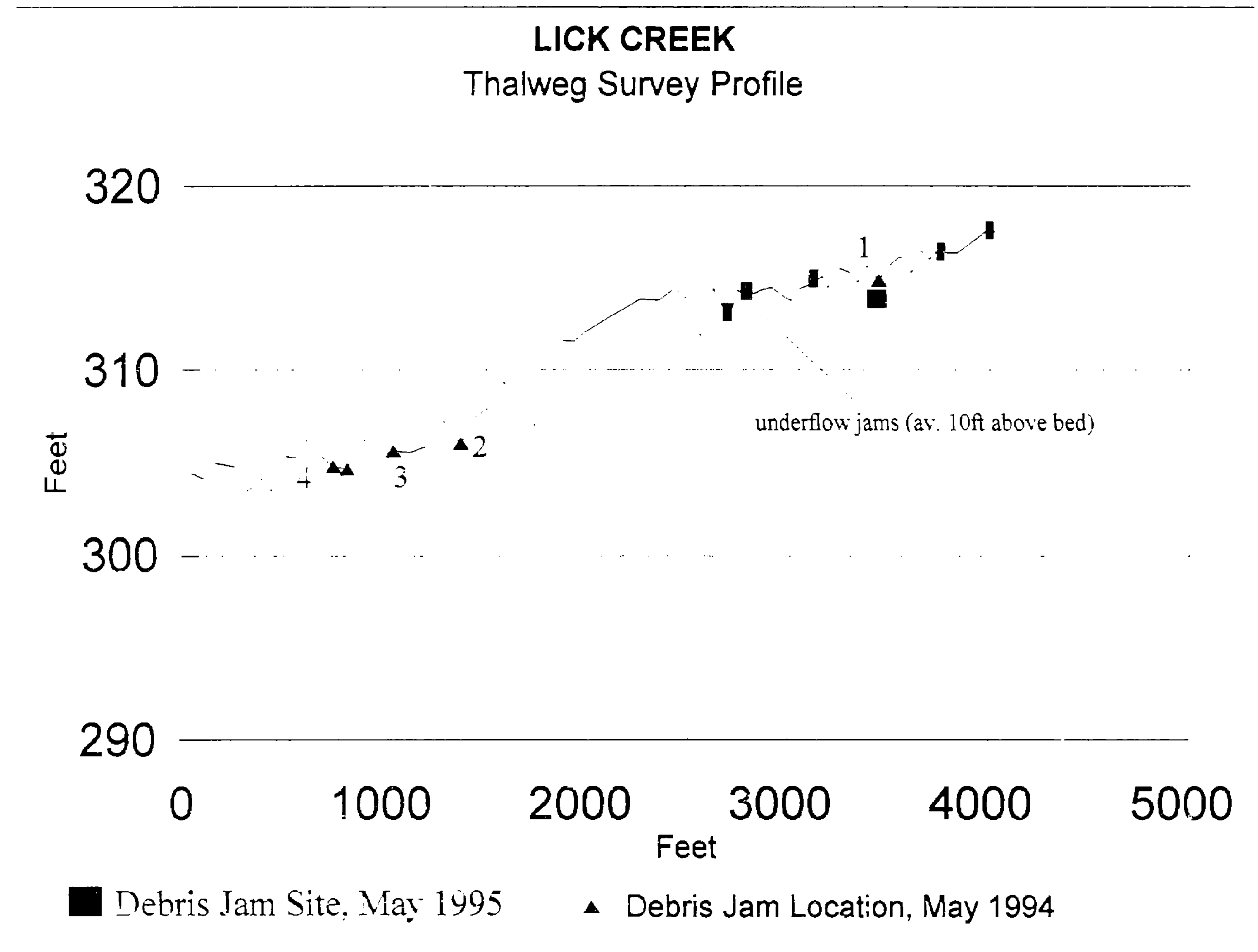


Figure 4.21 Long profile plot of Lick Creek : May 1994/95 data

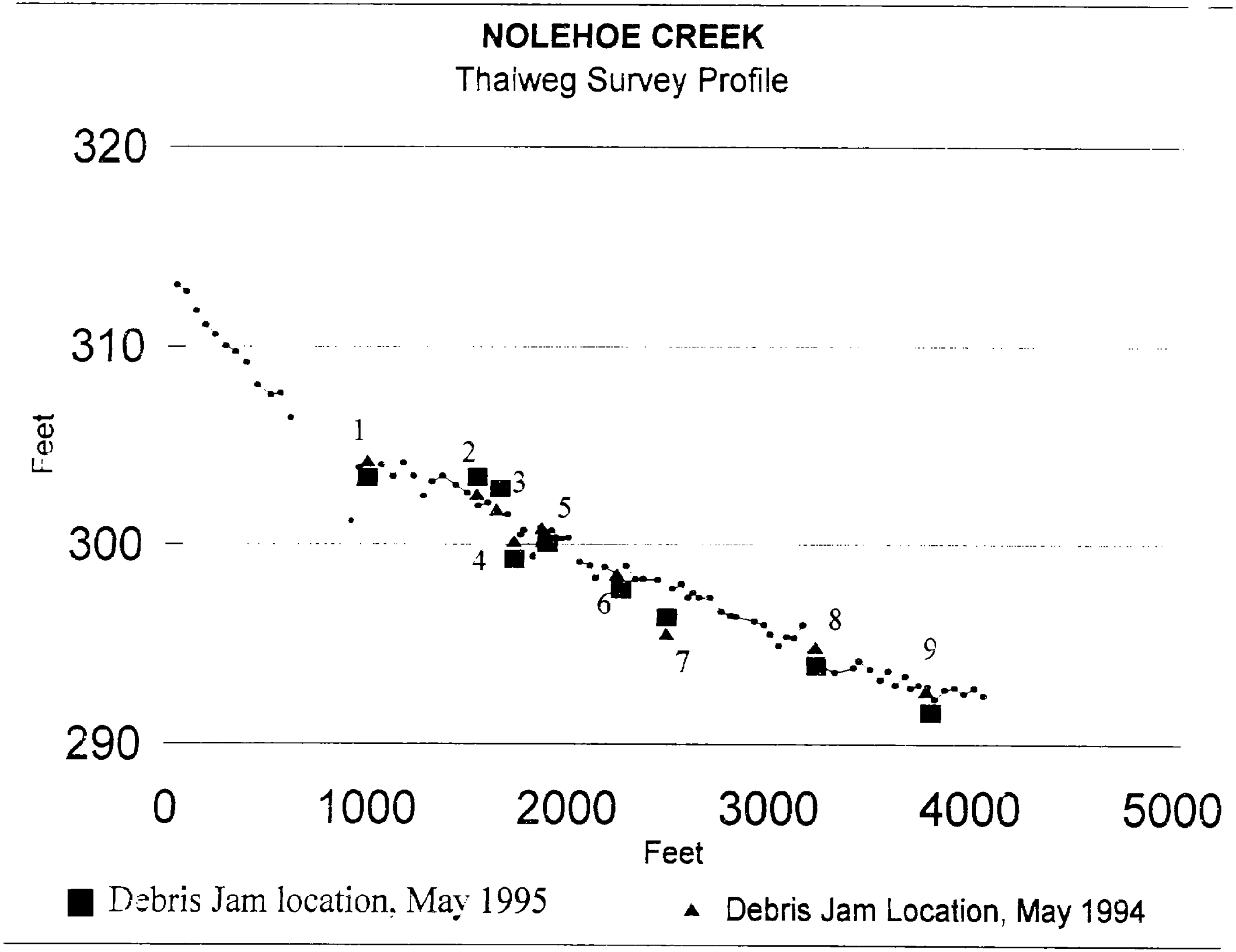


Figure 4.22 Long profile plot of Nolehoe Creek : May 1994/95 data

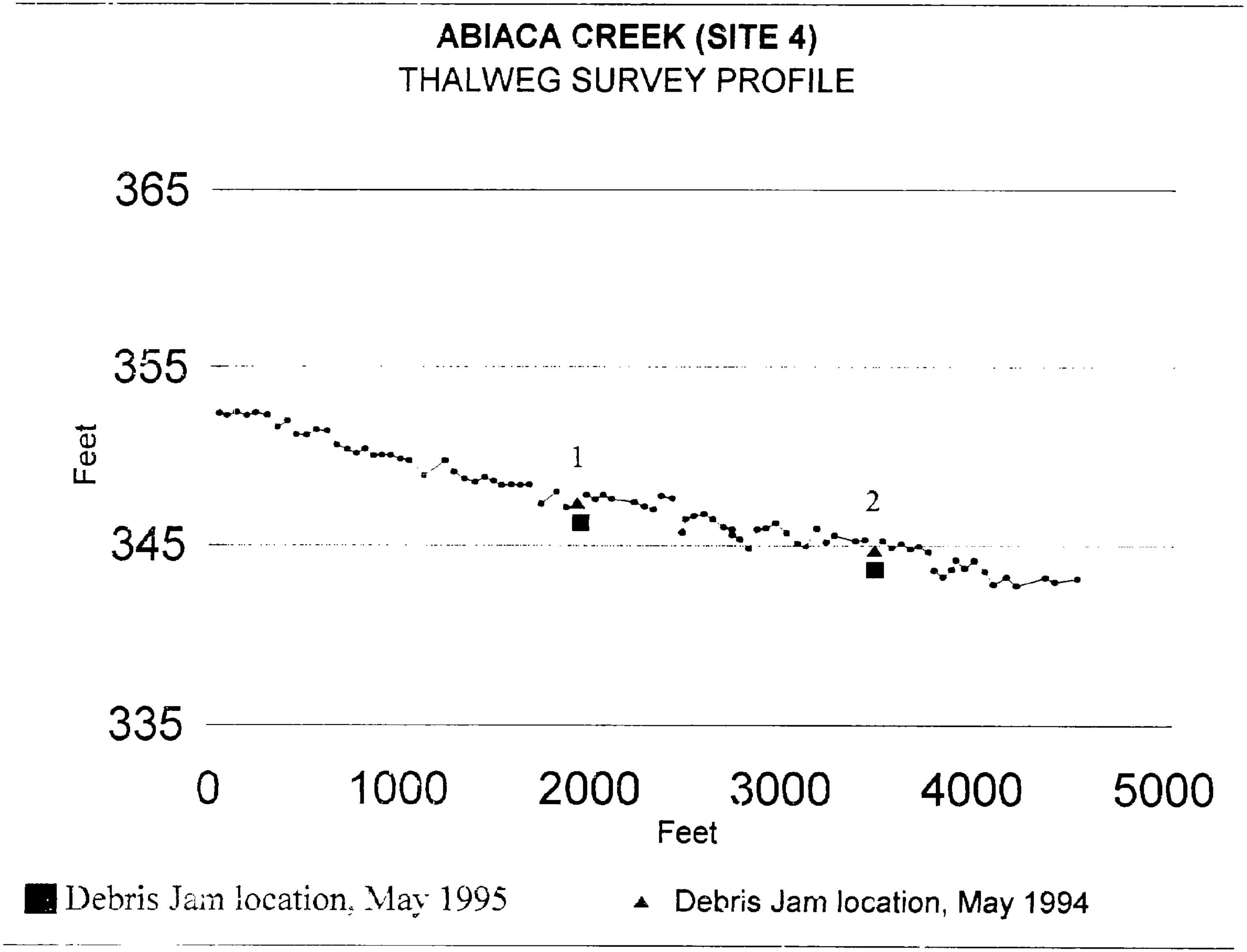


Figure 4.23 Long profile plot of Abiaca Creek, Site no 4 : May 1994/95 data

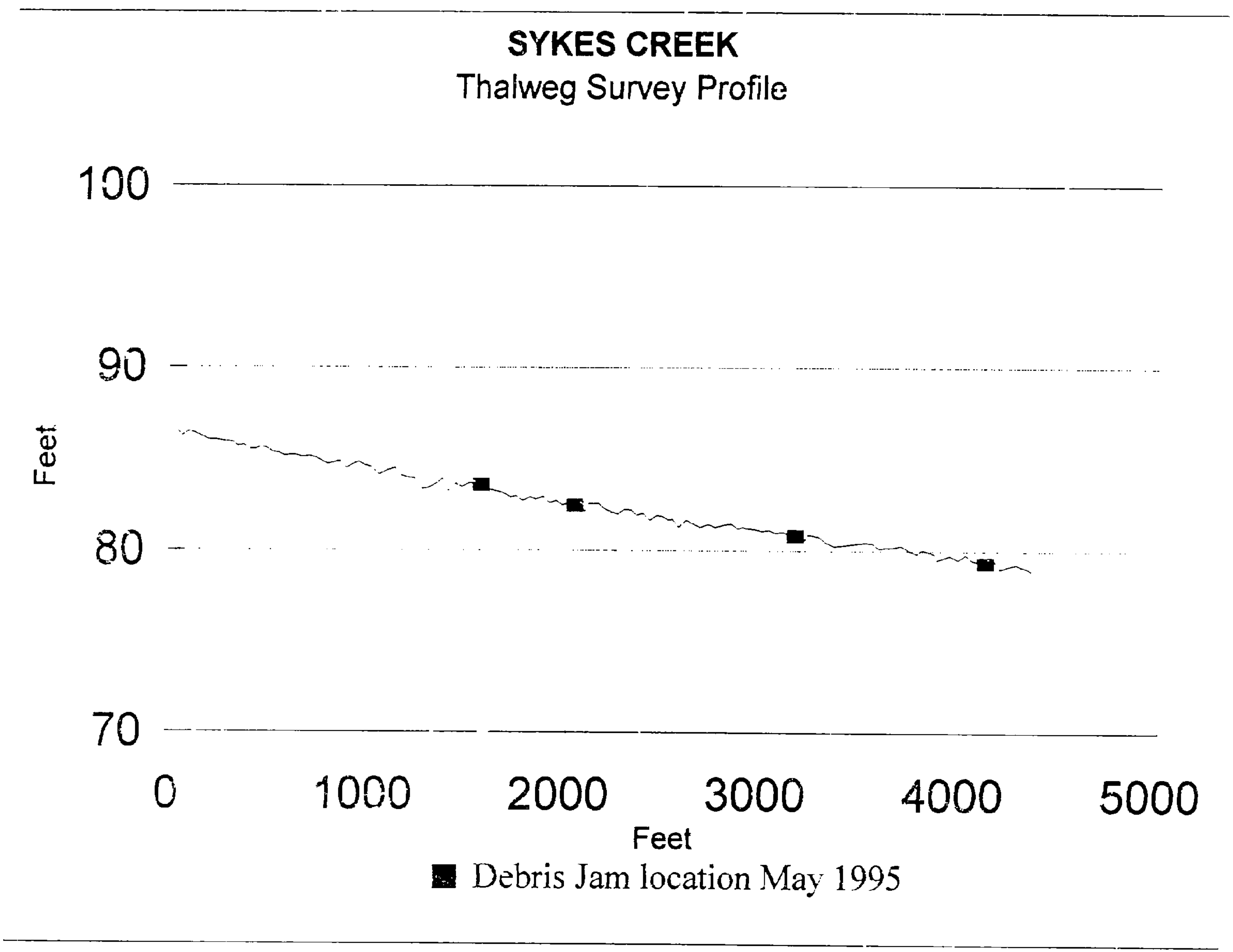


Figure 4.24 Long profile plot of Sykes Creek : May 1995 data

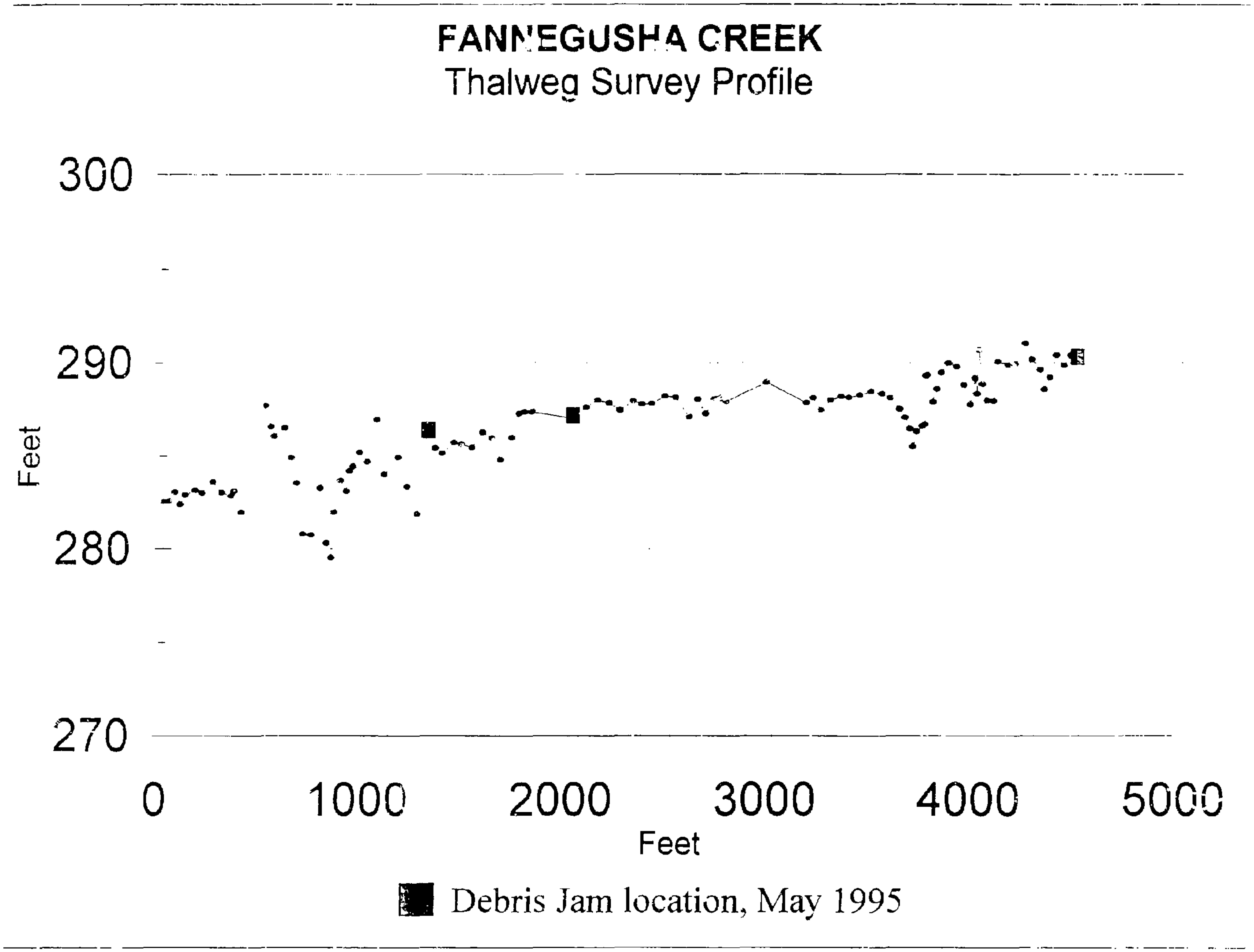


Figure 4.25 Long profile plot of Fannegusha Creek : May 1995 data

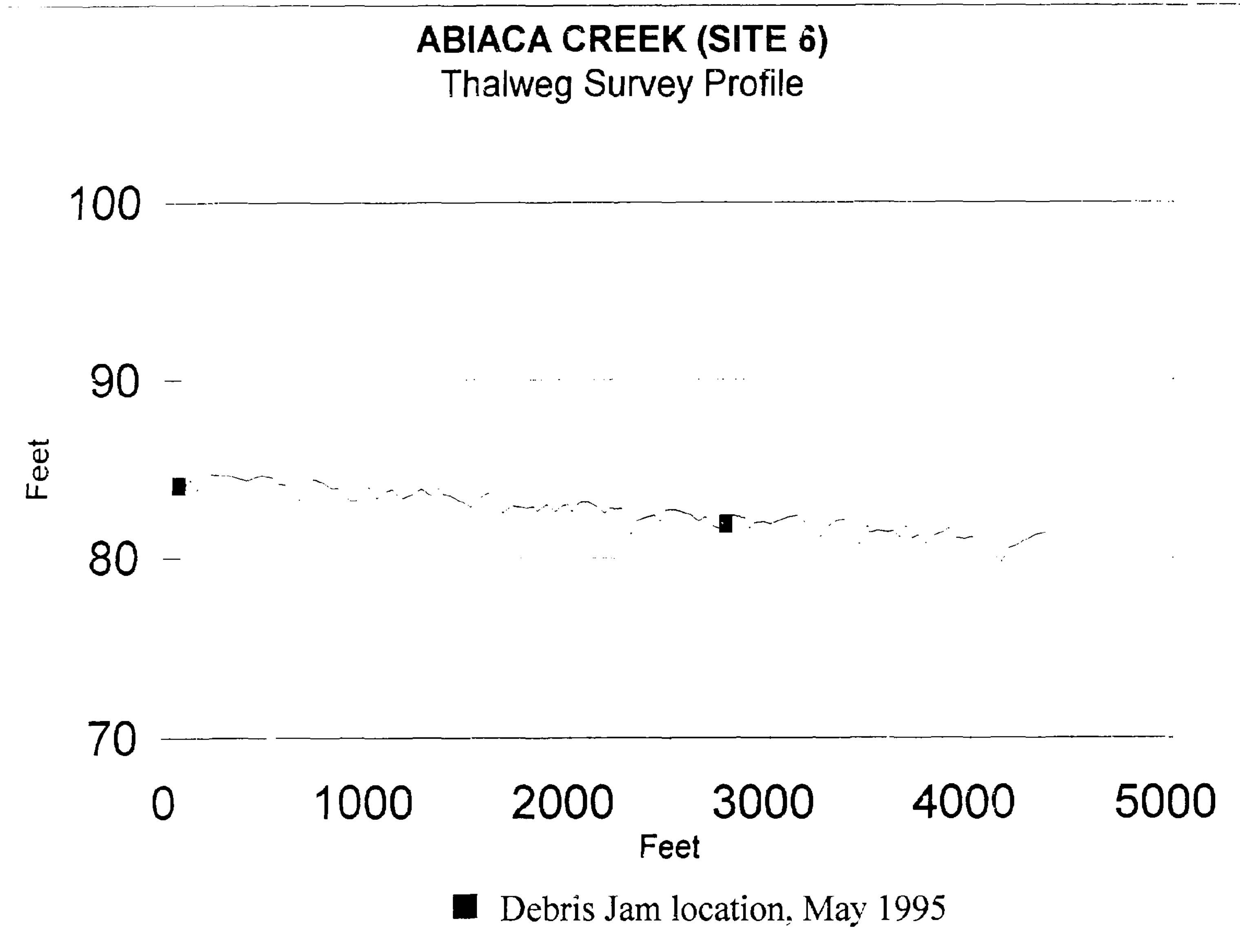


Figure 4.26 Long profile plot of Abiaca Creek, site no. 6 : May 1995 data

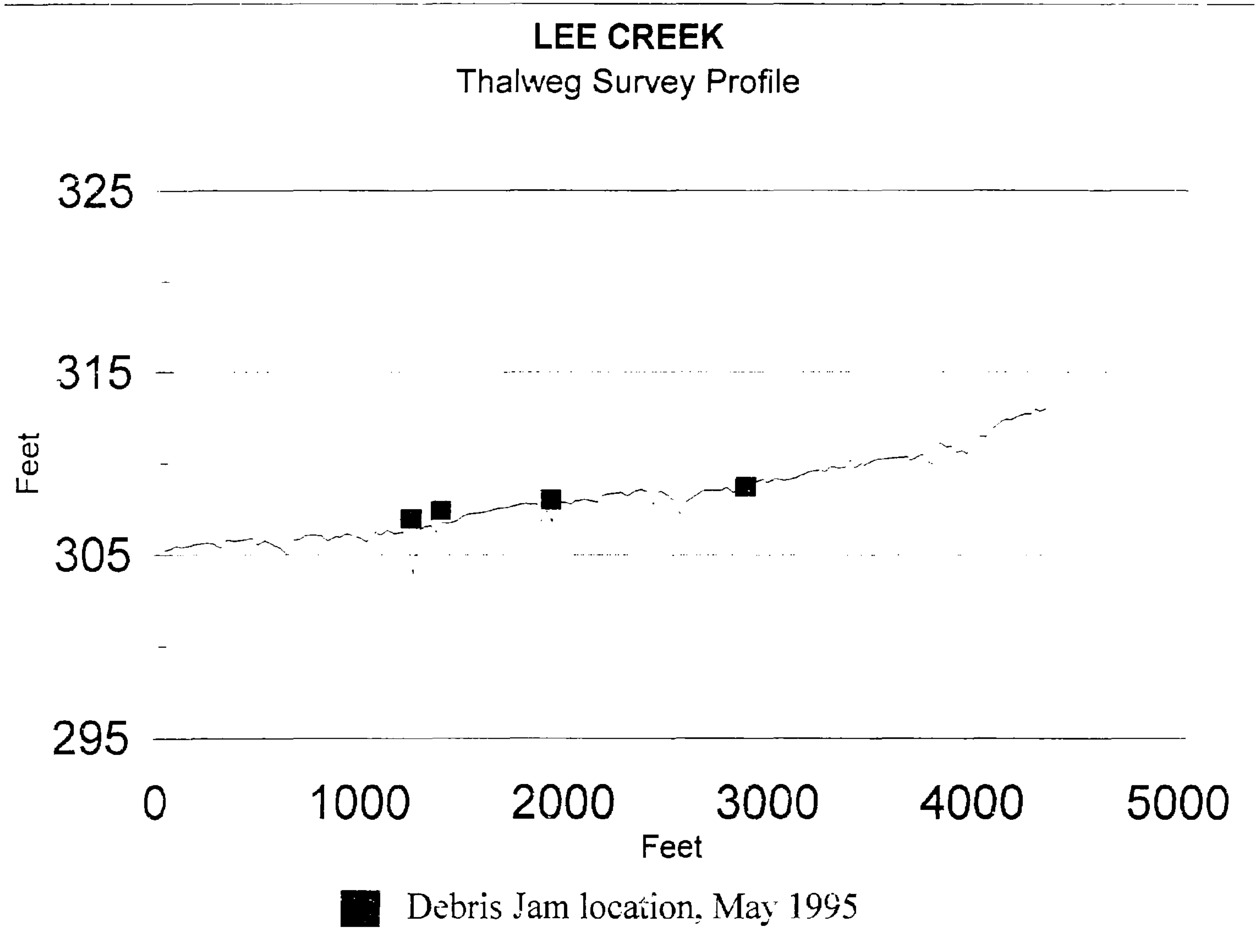


Figure 4.27 Long profile plot of Lee Creek : May 1995 data

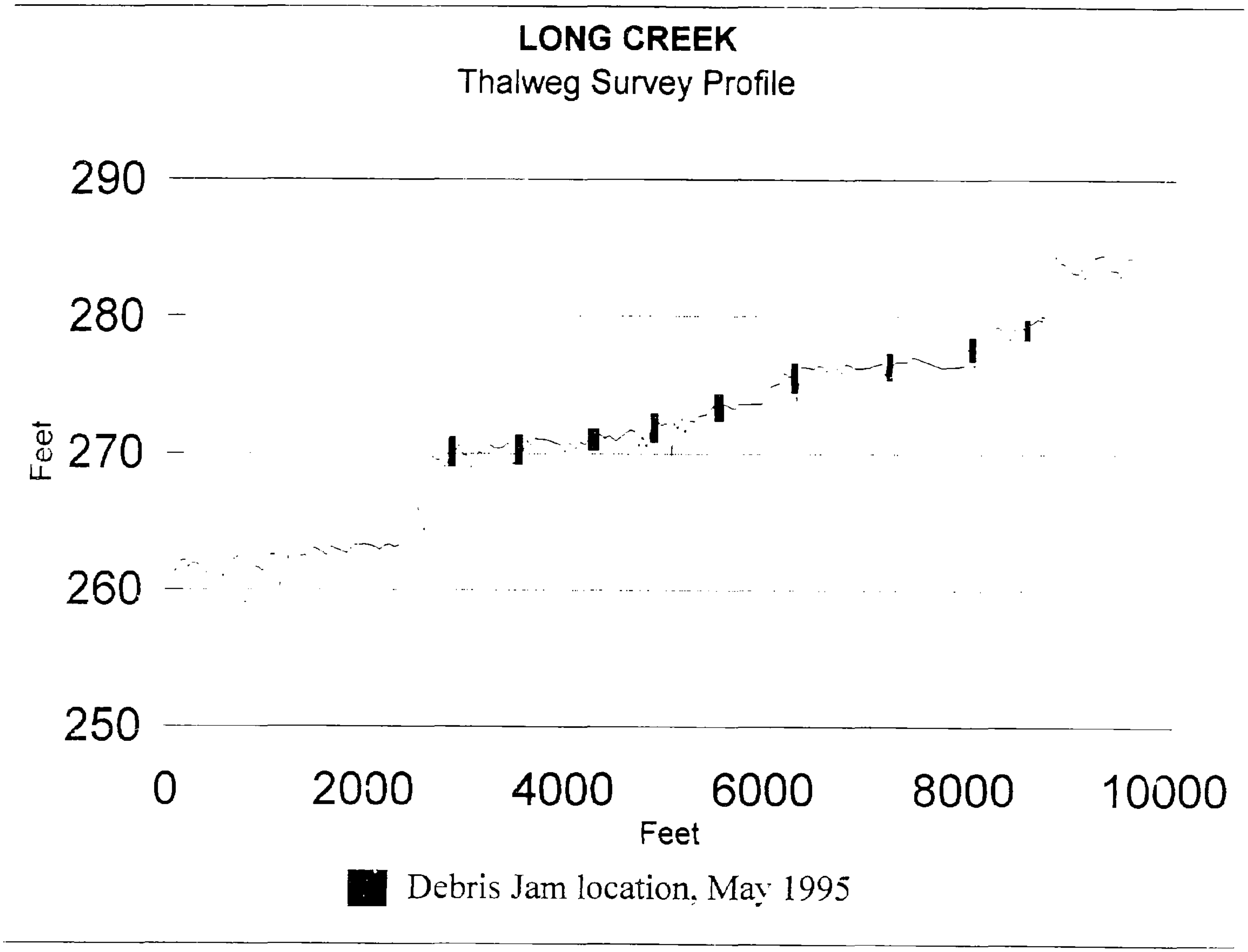


Figure 4.28 Long profile plot of Long Creek : May 1995 data

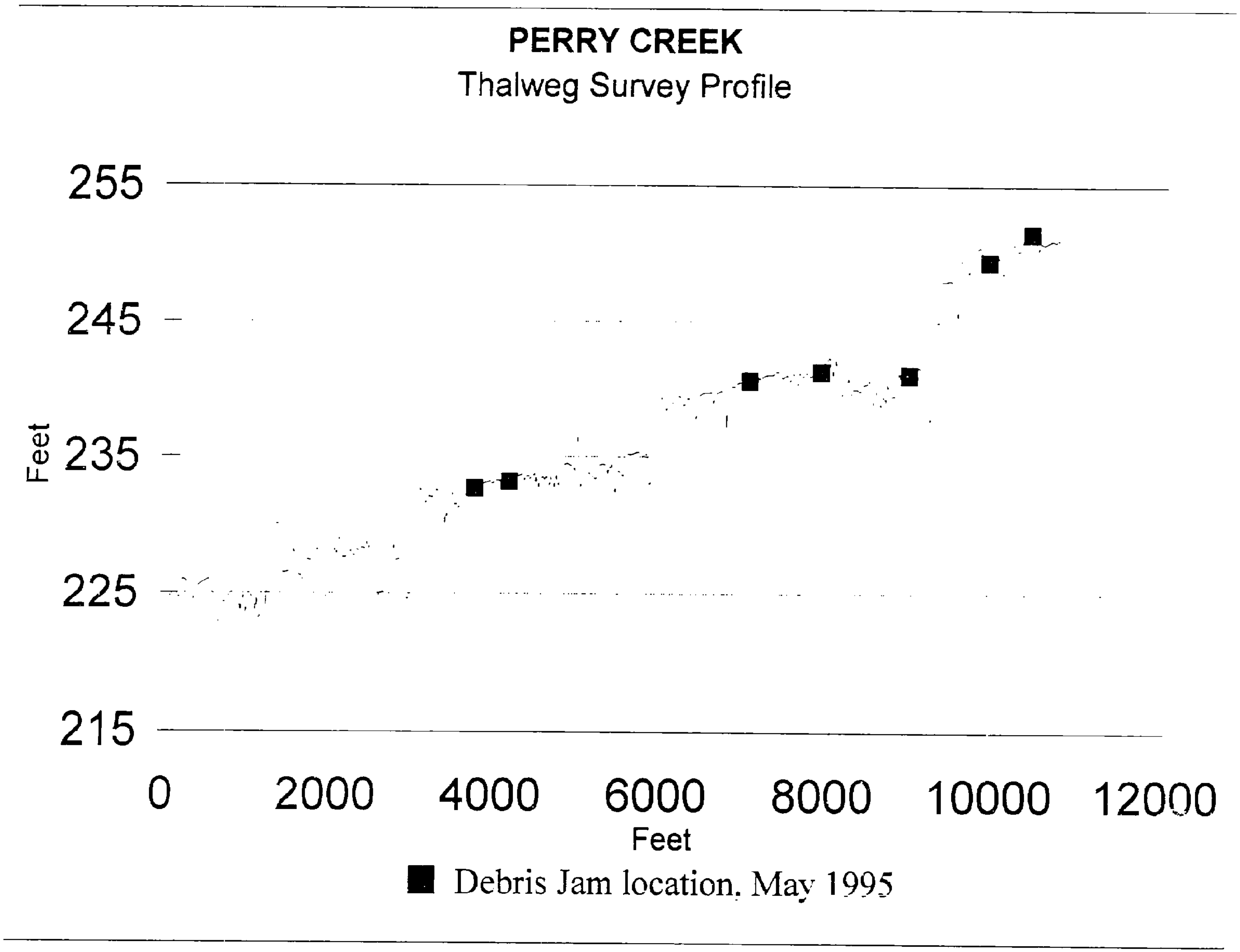


Figure 4.29 Long profile plot of Perry Creek : May 1995 data

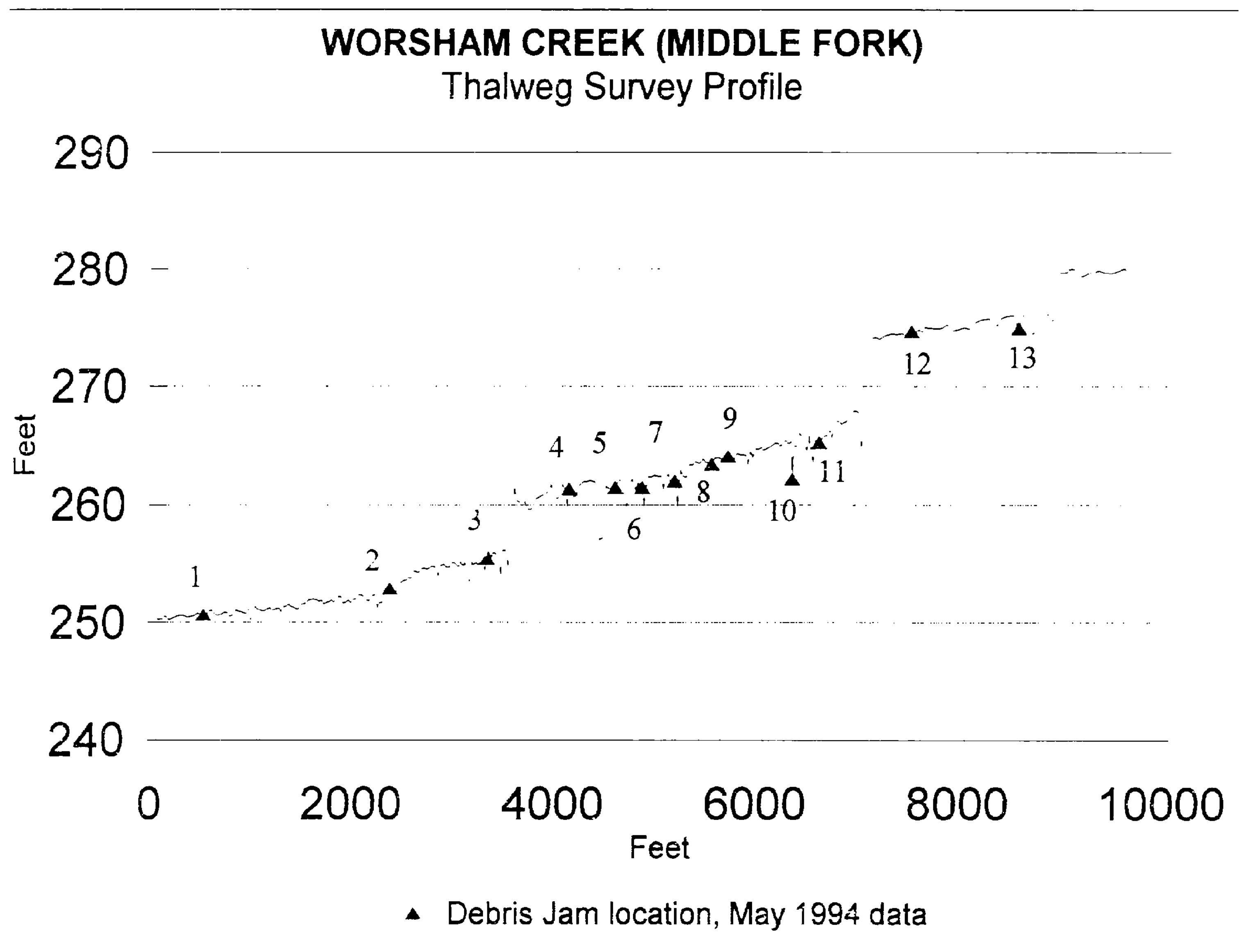


Figure 4.33 long profile plot of Worsham Creek (Middle Fork) : May 1994 data

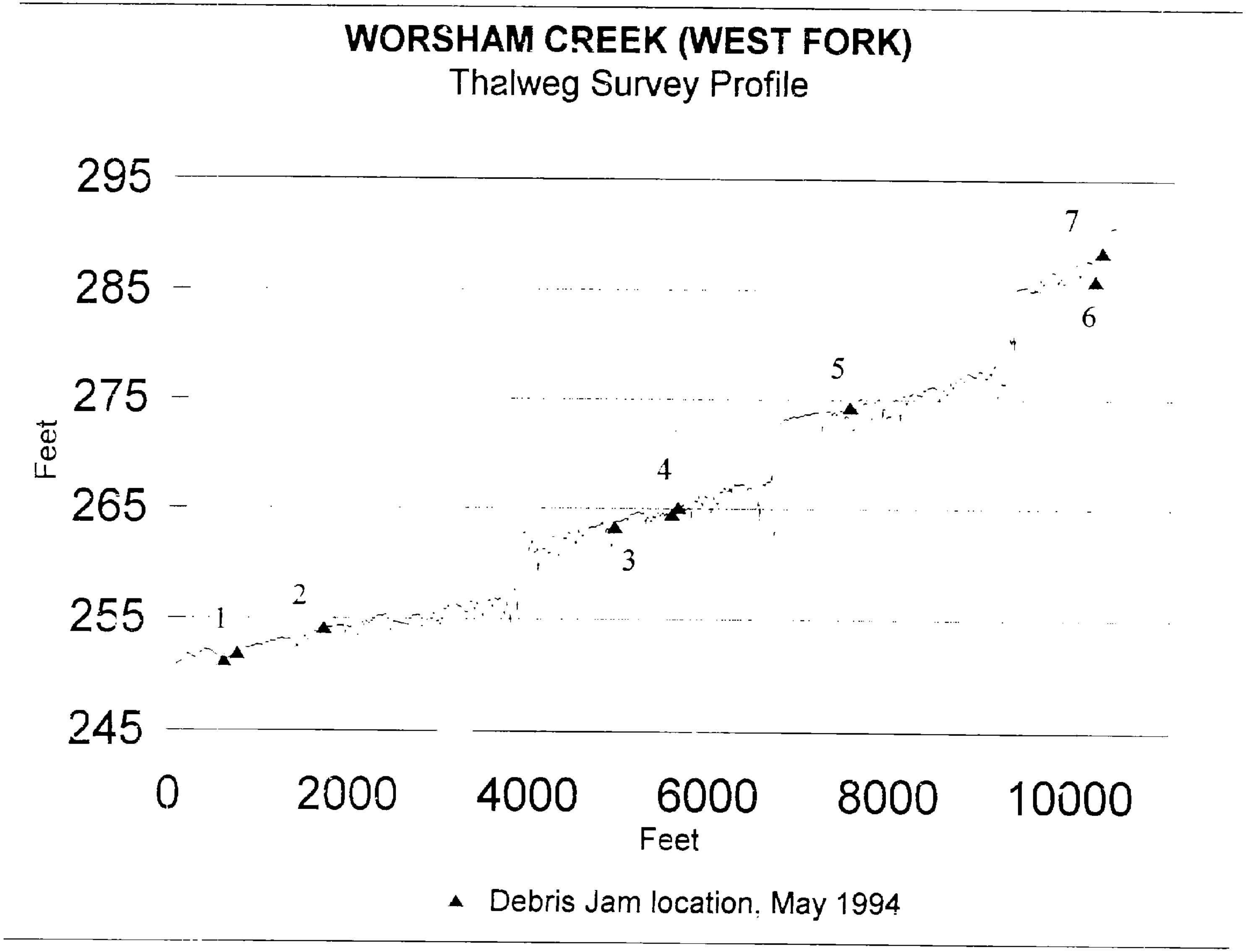


Figure 4.31 Long profile plot of Worsham Creek (West Fork) : May 1994 data

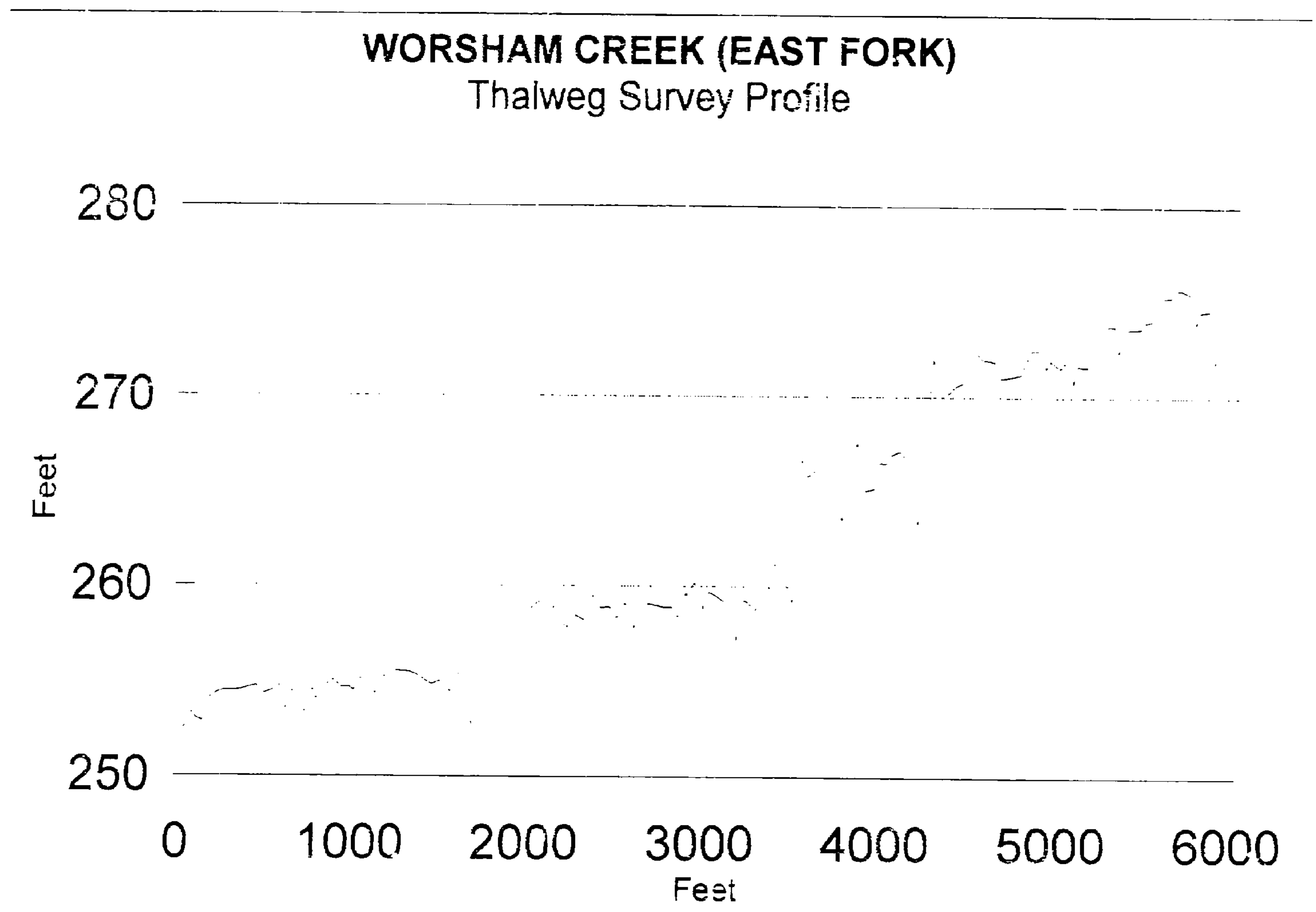


Figure 4.32 long profile plot of Worsham Creek (East Fork) : May 1994 data

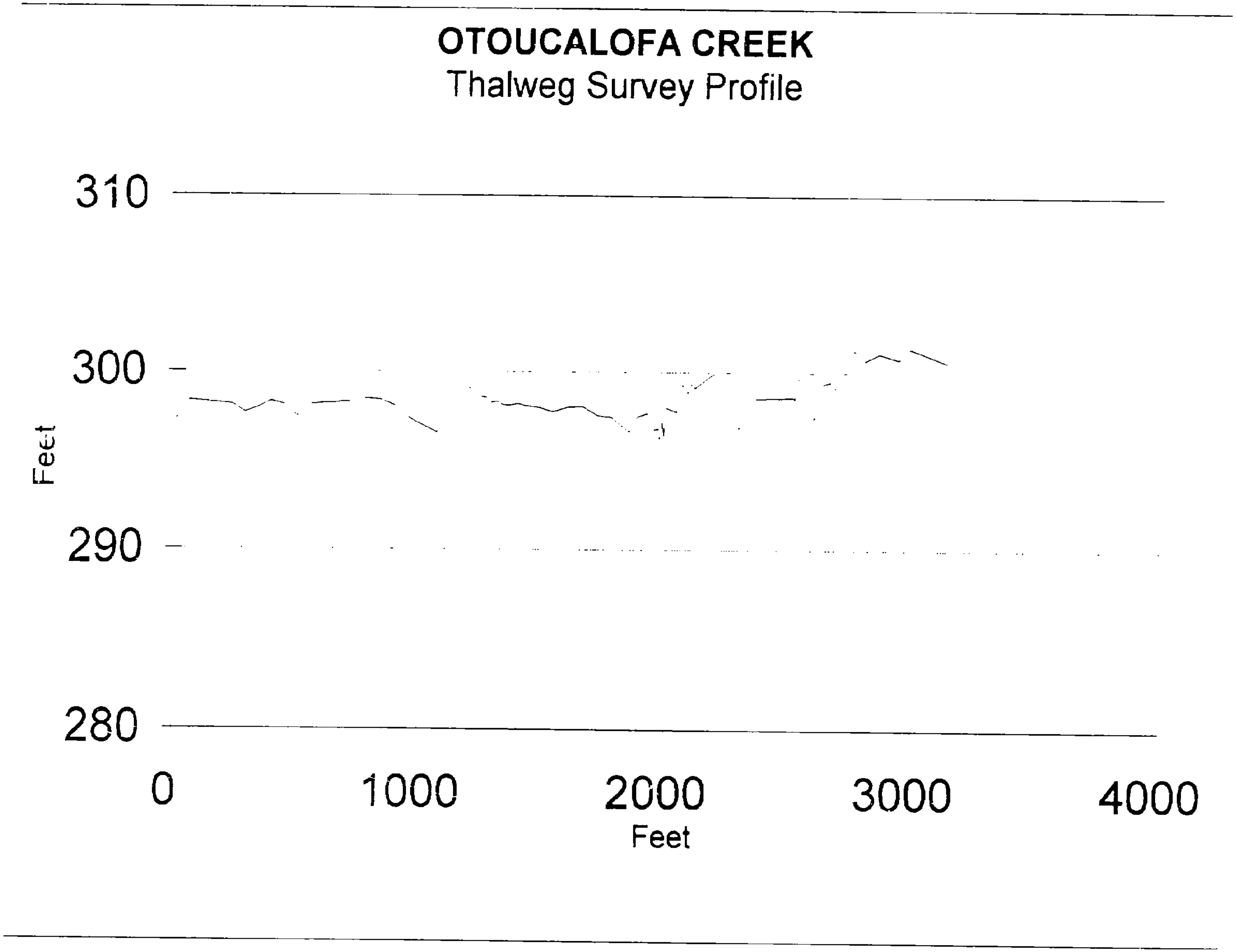


Figure 4.33 Long profile plot of Otoucalofa Creek : May 1994 data

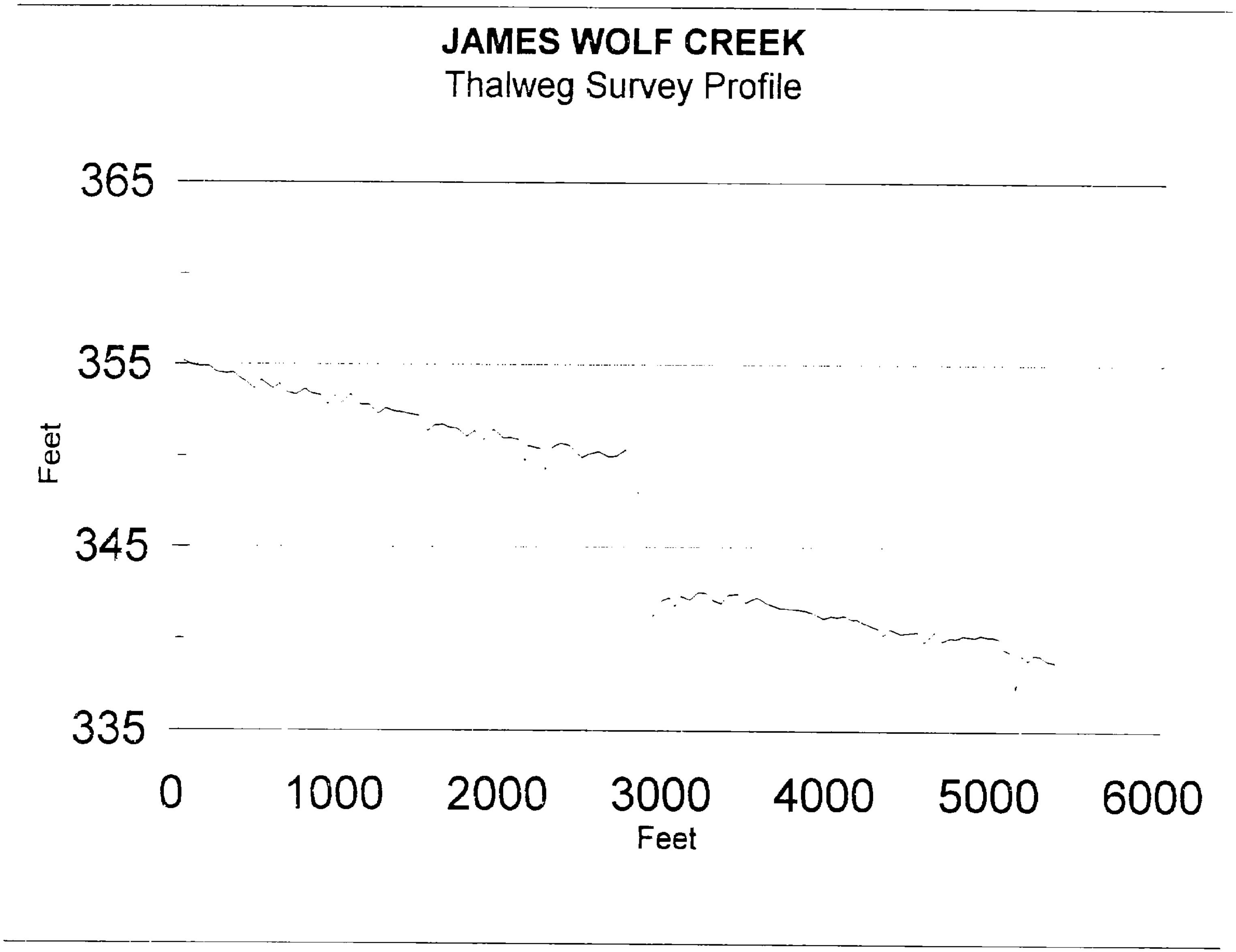


Figure 4.34 Long profile plot of James Wolf Creek : May 1994 data

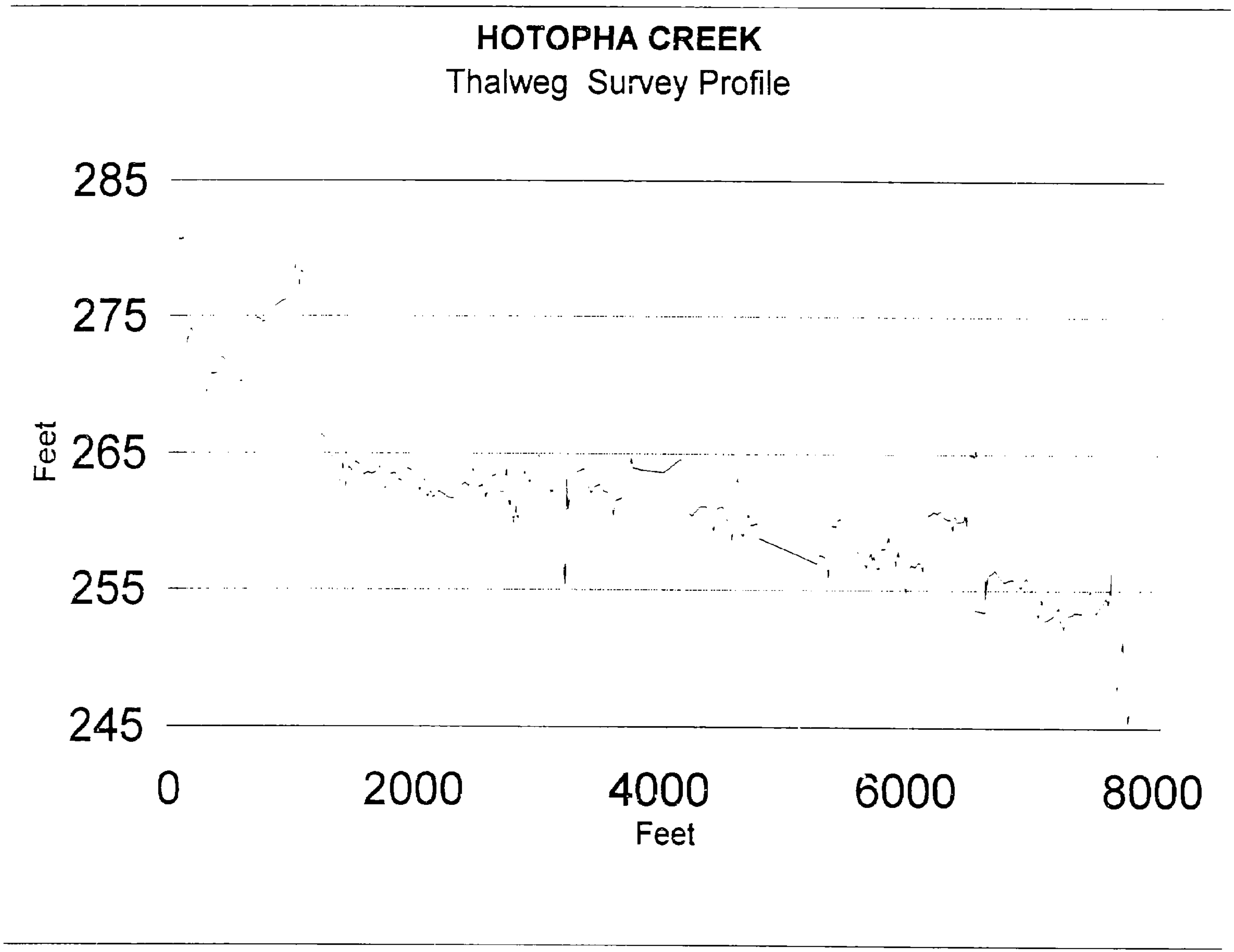


Figure 4.35 Long profile plot of Hotopha Creek : May 1994 data

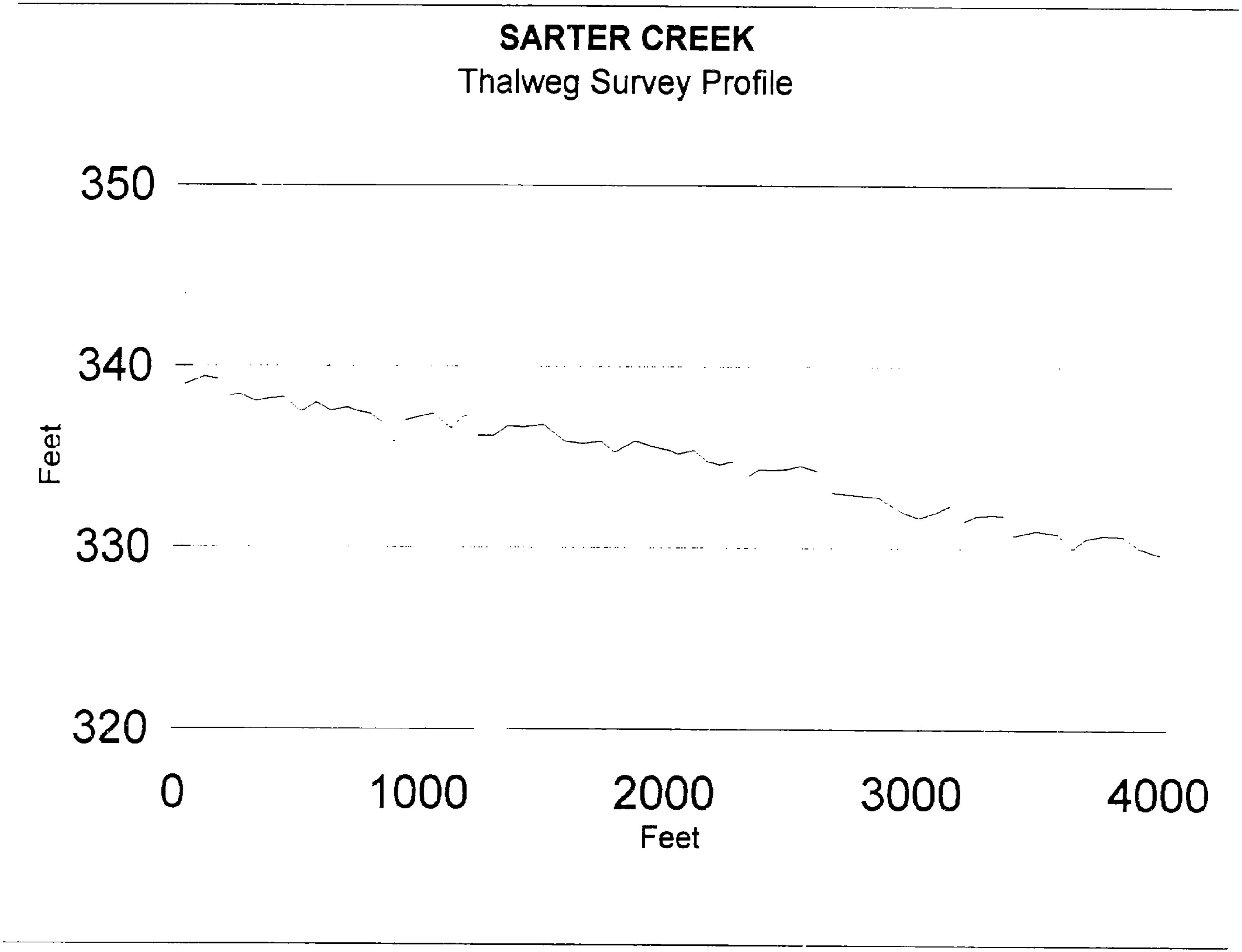


Figure 4.36 Long profile plot of Sarter Creek : May 1994 data

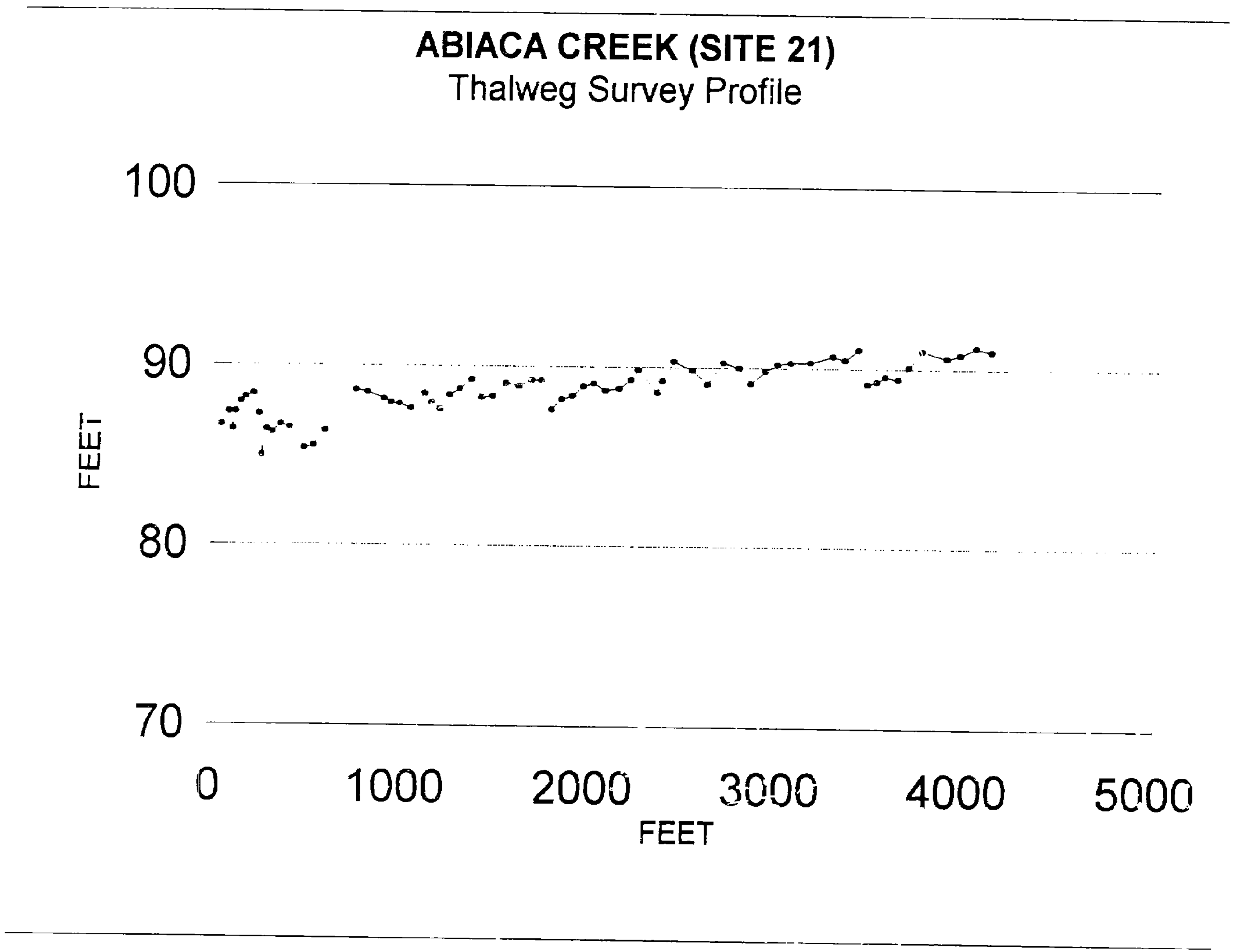


Figure 4.37 Long profile plot of Abiaca Creek, Site 21 : May 1994 data

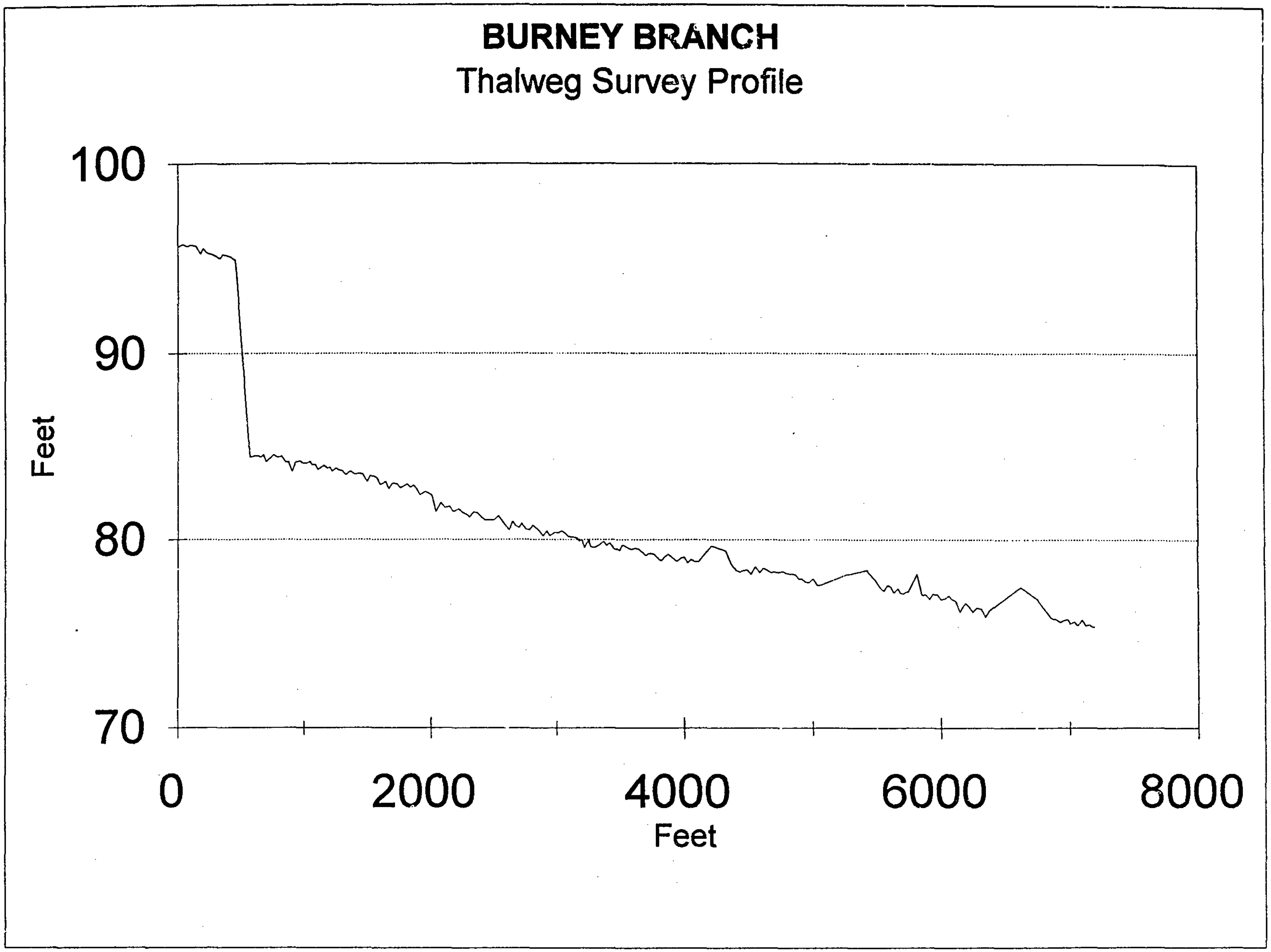


Figure 4.38 Long profile plot of Burney Branch : May 1994 data

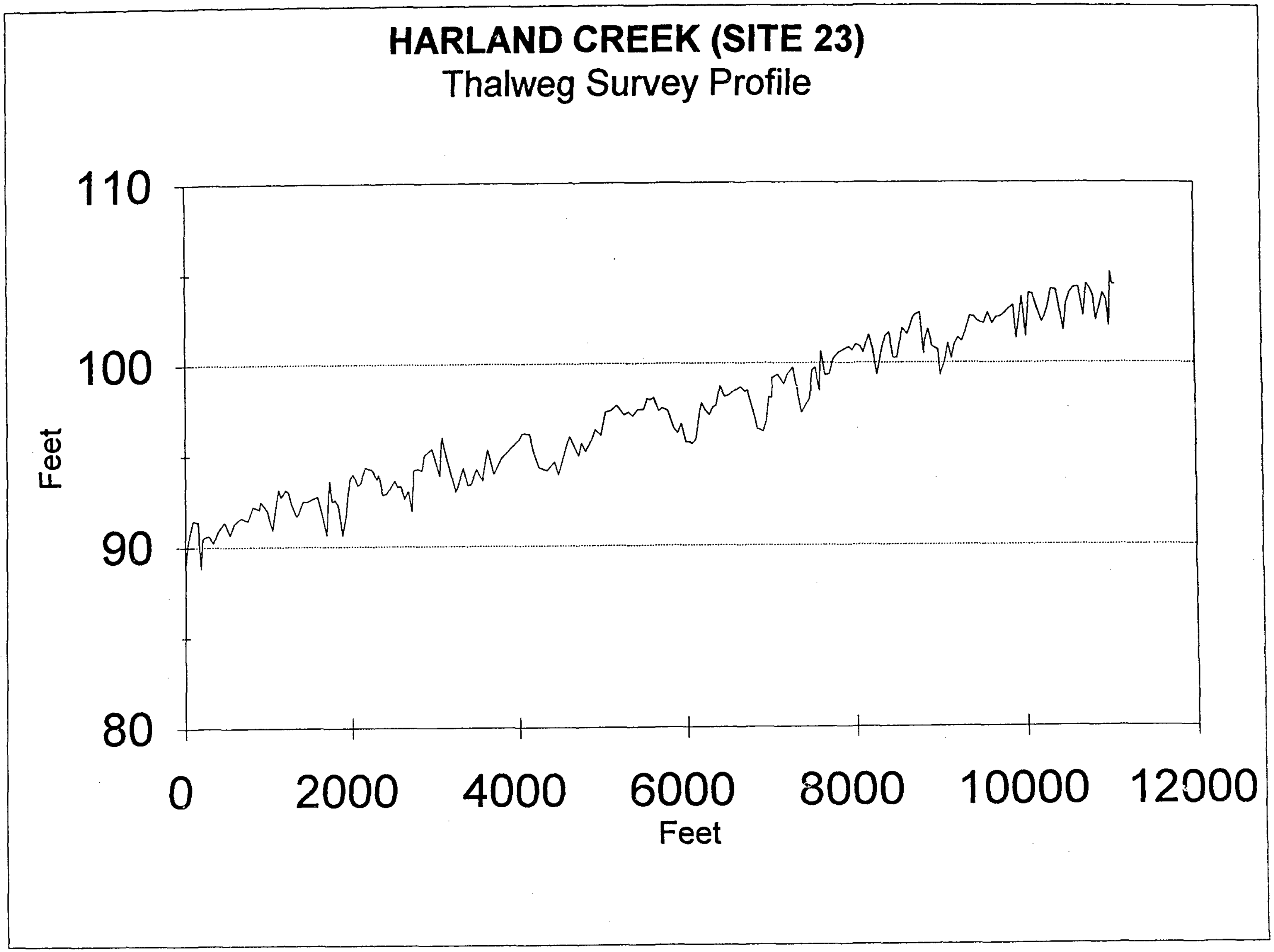


Figure 4.39 Long profile plot of Harland Creek, Site no. 23 : May 1994 data

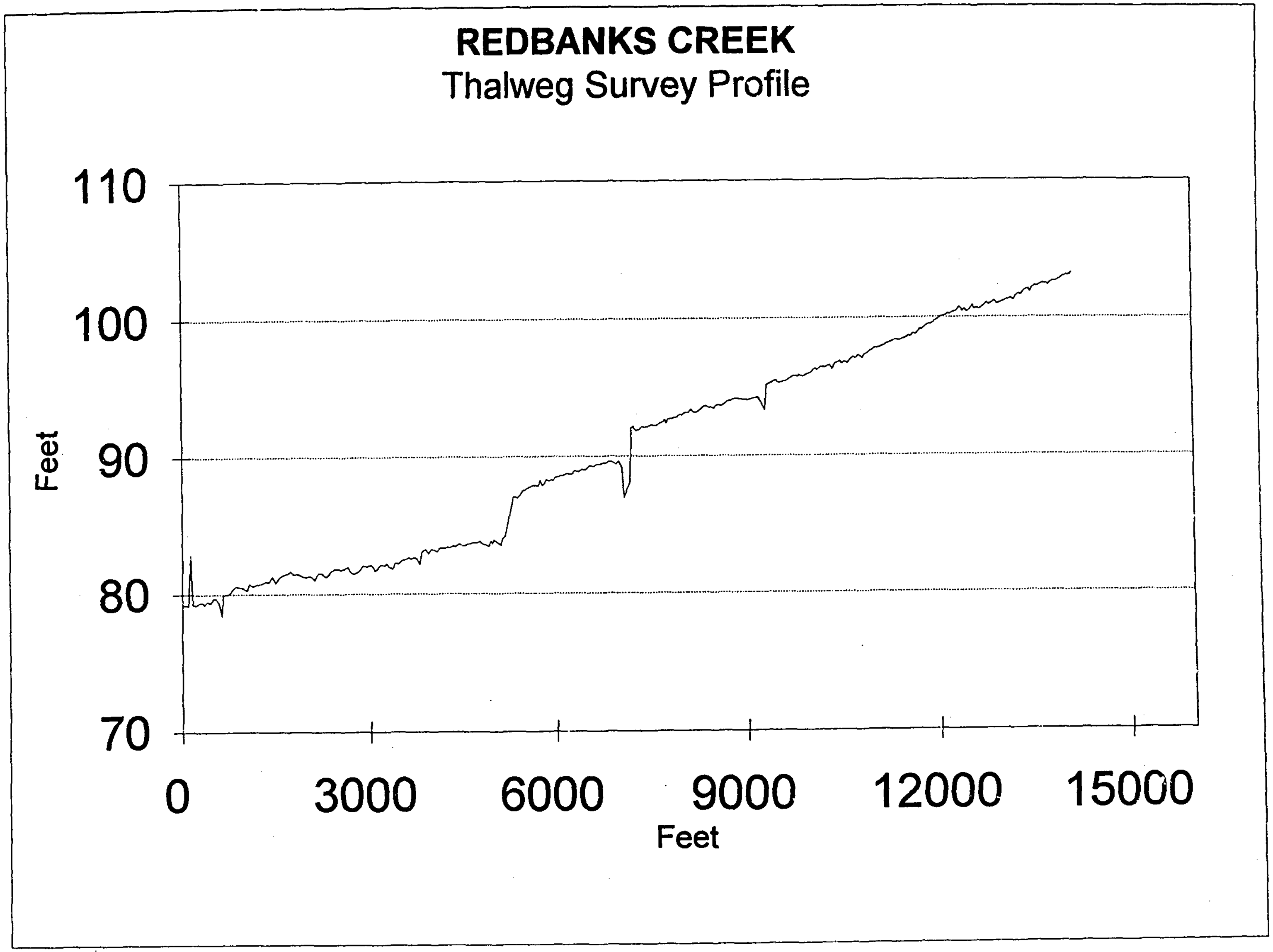


Figure 4.40 Long profile plot of Redbanks Creek : May 1994 data

5 COMPUTER MODELS

5.1 LARGE WOODY DEBRIS MANAGEMENT PROGRAM

The relationships between LWD formations and channel processes have been incorporated into a LWD Management Program. Version 1.0 of this program is included with this report on a disk. Appendix 1 a user manual for this program.

This is an updated version of the program to that which was included with the Project R&D 7258-EN-09, submitted to the US Army Corps of Engineers, June 1995 (Wallerstein, 1995).

This program predicts the jam type in a given reach, determines its impact upon the channel and outlines an appropriate management strategy. Inputs variables are those which have been found to be most critical in the LWD system and include channel width (determined from a catchment area function), average riparian tree height, reach sediment type and the riparian landuse type. The ratio of tree height to channel width is used to define the debris jam type present, with the precise limits of each classification determined from the empirical relationships. Sediment diameter is used to give an indication of the jams potential to induce backwater sedimentation or downstream bars. Debris jam types are classified using a scheme modified from Robinson & Beschta (1990), described in Wallerstein & Thorne (1994). Jam types are divided into **Underflow, Dam, Deflector** and **Flow Parallel**. Figure 5.1 shows this classification scheme. The program output takes the form of a text file which describes the classification chosen, and offers basic in-channel LWD management strategies. While the management strategies are based solely on theoretical considerations, the program never-the-less provides a framework for future model development as empirical relationships between the variables are better characterised. A flow diagram of the computer program is shown in figure 5.2.

The program has also been linked to a GIS (Geographical Information System) front end which has been constructed by Peter Cheeseman, a masters student at Nottingham University (see Cheeseman, 1995). The project was carried out to demonstrate the potential for using GIS as a platform for data input to expert systems to aid engineers with river basin management.

The GIS was constructed in ARC Info using data layers, supplied by the WES Intergraph data-base, for the Abiaca Creek watershed and provides automatic data input, for the necessary variables and a platform for running the program. This watershed was selected because it contains four debris survey reaches which are being monitored in the current research. The theoretical model can therefore be tested against the empirical data results from the field studies, and be validated and further developed. This management model is simple, but provides a framework for future development as empirical relationships between variables are better characterised.

Figure 5.1 Revised Debris Jam Classification Scheme

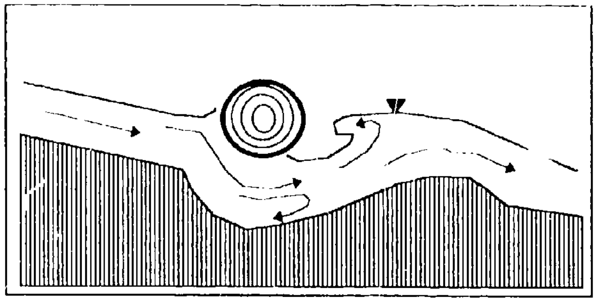
Increasing drainage basin area / discharge

Decreasing jam residence time / increasing vol. of debris in transport

UNDERFLOW JAM

DEBRIS LENGTH > CHANNEL WIDTH

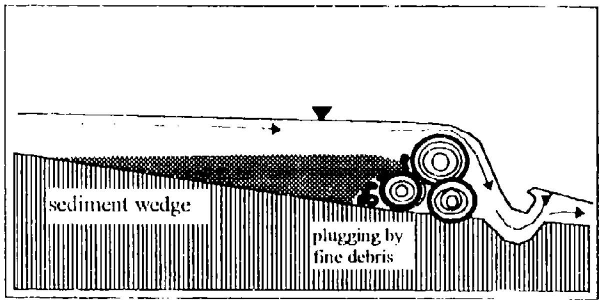
Impact : local bed scour & limited backwater sedimentation



DAM JAM

DEBRIS LENGTH = CHANNEL WIDTH

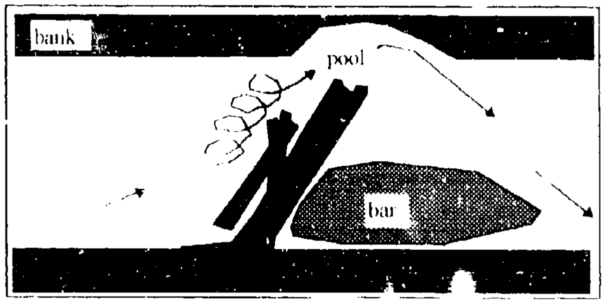
Impact : backwater pools & log steps, sediment wedge formation in gravel bed rivers, bed/bank scour in sand bed rivers



DEFLECTOR JAM

DEBRIS LENGTH < CHANNEL WIDTH ;
> 0.25 x CHANNEL WIDTH

Impact : flow deflection, bed scour & bank erosion, local channel widening bar devt. in lee of jam.

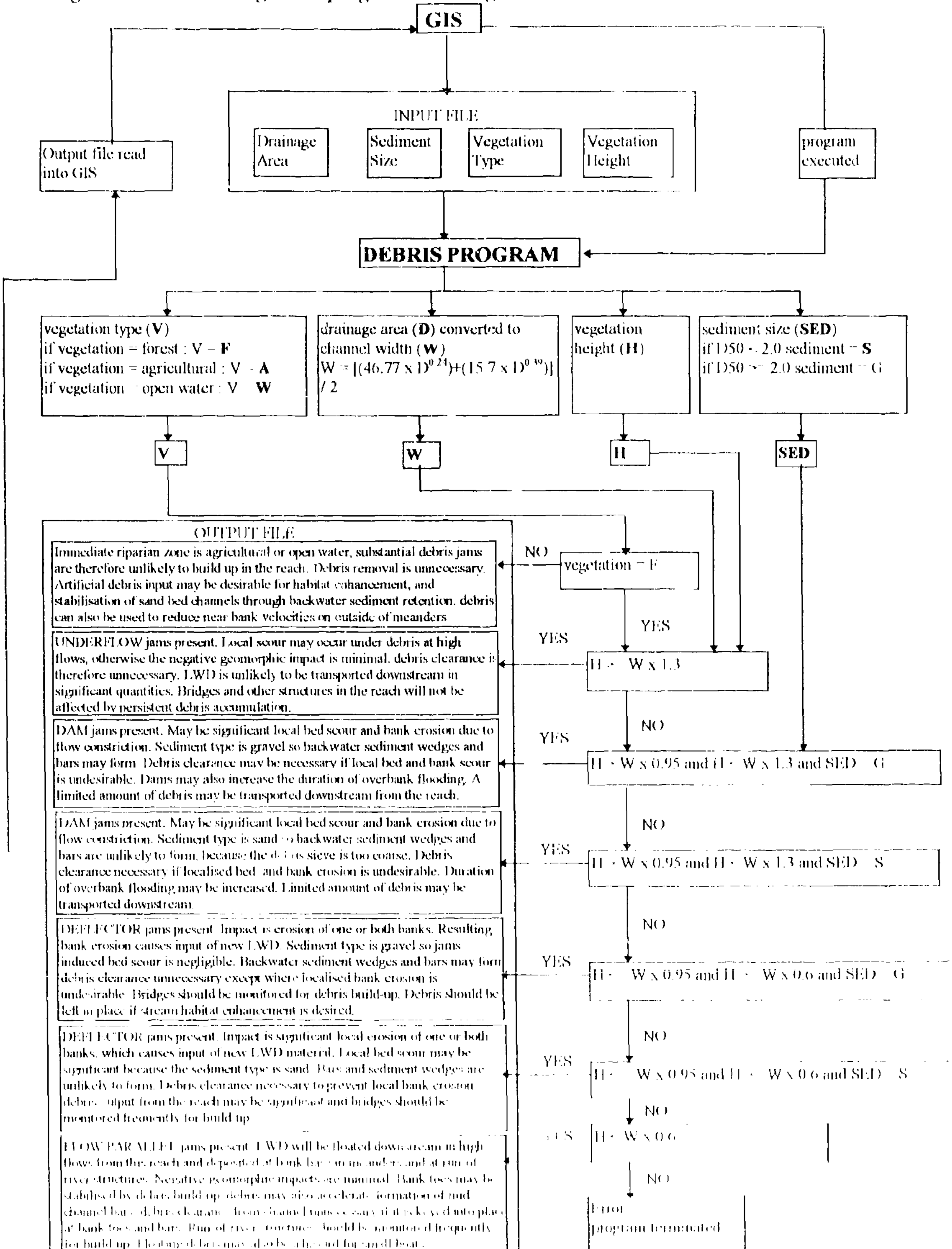


PARALLEL / BAR HEAD JAM

DEBRIS LENGTH < 0.25 x CHANNEL WIDTH

Impact : bank toe protection by parallel debris Accelerated incipient bar growth

Figure 5.2 LWD management program flow diagram



5.2 DEBRIS AT BRIDGE PIER PREDICTION PROGRAM

This program calculates the probability of debris build-up at bridge piers, and the associated debris induced scour, based upon modified theoretical equations published by Melville and Dongol (1992) and Simons and Li (1979). Version 1.0 of this program is also included on the enclosed disk. Appendix 2 contains a user manual for this program

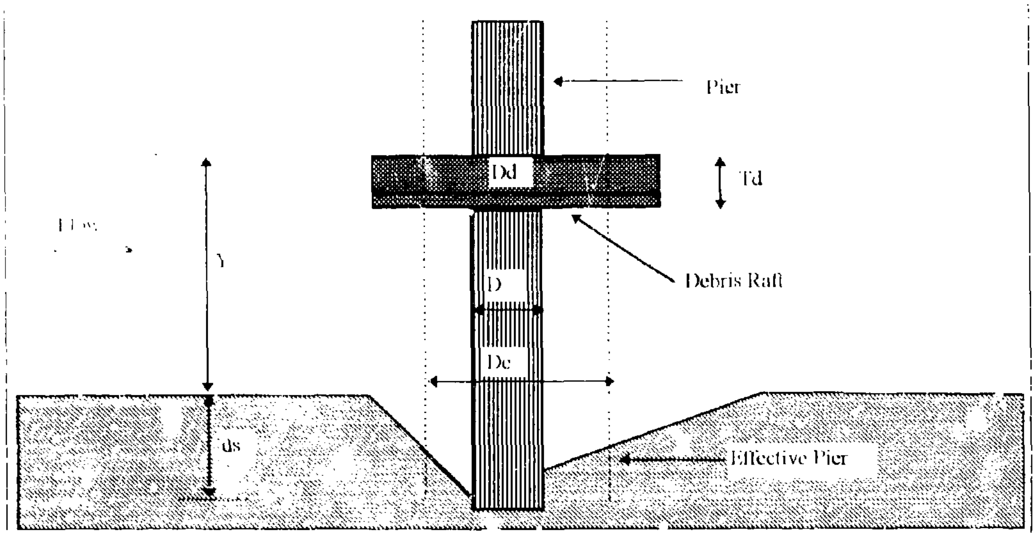
5.2.1 Bridge Scour Model with Debris Build-up

There are only a limited number of studies that have addressed the problem of debris accumulations at bridges. Melville & Dongol (1992) look at the problem of pier scour due to debris, while Simons & Li (see Callander, 1980) have used a probabilistic approach to quantify the rate of bridge span blockage by debris and the subsequent backwater effect and pressure forces generated on the piers.

Local scour at bridge piers has been extensively investigated. However the impact of debris rafts at piers which create additional flow obstruction and therefore increase scour depths has been largely neglected. A design method for estimation of scour depths at piers is presented by Melville and Sutherland (1988), based on envelope curves from laboratory data. The largest local scour depth at a cylindrical pier is estimated to be 2.4D where D is the pier diameter. This value is reduced, however, using multiplying factors where clear-water scour conditions exist, the flow is relatively shallow, and the sediment size relatively coarse. In the case of non-cylindrical piers, additional multiplying factors are applied to account for piers shape and alignment. Consideration of the likelihood of debris build-up is not addressed by Melville and Dongol (1992) but they do note, however, that single cylindrical piers are the least likely shape to accumulate debris, and that the free space between columns is seldom great enough to pass debris. Prediction of the size of possible debris raft accumulations remains the biggest problem for accurate factor of safety calculations.

The experimental arrangement used by Melville and Dongol is shown in Figure 5.3.

Figure 5.3 Experimental Set-up (modified from Melville and Dongol, 1992).



The design curve for pier scour without debris accumulations, developed by Melville and Sutherland is described by the following two equations:

$$\frac{ds}{D} = 1.872\left(\frac{Y}{D}\right)^{0.255} \qquad \left(\frac{Y}{D} < 2.6\right) \tag{5.1}$$

$$\frac{ds}{D} = 2.4 \qquad \left(\frac{Y}{D} \geq 2.6\right) \tag{5.2}$$

This shows that scour depth increases with increasing flow depth towards a limiting value for Y/D < 2.6. The same trend is found for piers with debris accumulations for values of Y/D < 4. At higher values of Y/D scour depths decrease again because the proportion of pier length covered by debris decreases. For deep flows the effect of debris would become insignificant and tend towards the value ds/D = 2.4.

The effective diameter of a pier with a debris accumulation, De, is given by,

$$De = \frac{Td^{*}Dd + (Y - Td^{*})D}{Y} \tag{5.3}$$

According to equation 5.3 De is calculated as a weighted average of an effective length Td* = 0.52Td of the debris raft with diameter Dd and a length of the pier (Y − Td*) with diameter D (see figure 5.3). The factor 0.52 was determined by evaluating the limits of Td and Dd/D for the hypothetical case where D is assumed to be zero and the debris is assumed to extend to the base of the scour hole.

D can therefore be substituted for De to calculate scour depth at piers with debris accumulations using the Melville and Sutherland design method. Conversely a maximum allowable Td and Dd can be calculated by specifying an upper scour depth within an acceptable factor of safety for a given pier size.

5.2.2 Probability based debris build-up model

The rate of debris accumulation at a bridge is difficult to quantify. The only method found in the literature is that presented by Simons & Li (1979) in an MSc thesis by Callander (1980) entitled "Fluvial processes occurring at bridge sites".

According to Simons & Li, the trapping efficiency of a bridge is determined by:

1) Clearance beneath the bridge
2) Span lengths
3) Size and concentration of debris elements

The following possible consequences are identified which can result from debris blockage:

1) Backwater effects
2) Potential local flow diversion
3) Channel avulsion
4) Bridge failure

Simons & Li express the volume of debris as a fraction of the sediment yield, and suggest a vegetation debris yield of 1%. In an attempt to estimate the number and volume of trees arriving at a bridge they utilise the volume of flood-plain erosion necessary to yield a tree, and use a representative tree size for the watershed.

Trees are assumed to be cylindrical with a diameter Dt, and a height Ht. The span between piers is Ls and the clearance between the water surface and the underside of the bridge is C. The chance that a tree will be trapped depends on a larger diameter however, Db, which represents either the canopy dimension or the root zone, whichever is larger. See figure 5.4.

If Ht > Ls the probability of at least one average tree being trapped is 100%. The blocked area is then estimated to be, NHtDt, where N is the equivalent number of average trees assumed to be trapped against the upstream face of the bridge.

If Ht < Ls a probabilistic approach is used

Pt is the probability of a tree being trapped, and as the blockage beneath a span increases so the chance of other trees being trapped increases. The probability of the first tree being trapped is assumed to be a ratio of half the tree diameter, Db, to the total waterway area beneath a span, LsC

$$PT1 = \frac{\frac{1}{2}\left(\pi Db^2 / 4\right)}{LsC} = \frac{\pi}{8}\frac{Db^2}{LsC} \tag{5.4}$$

Li (see Callander, 1980) observed that a tree caught on a pier will in general lie with its trunk in the direction of flow. A tree thus trapped offers an area of

$$\tfrac{1}{2}\left(\pi Db^2 / 4\right) = \pi / 8 Db^2 \tag{5.5}$$

to trap other debris.

In general when (m-1) trees are trapped beneath a span the probability of an mth tree becoming trapped is

$$PTm = \frac{\pi Db^2 / 8}{LsC - (m-1)(\pi Db^2 / 8)} \tag{5.6}$$

The probability of passing all NT trees from the watershed is

$$(1-PT1)^{NT} \tag{5.7}$$

The probability of at least one tree being trapped at a span is

$$P1 = 1-(1-PT1)^{N} \tag{5.8}$$

where N is the equivalent number of average trees arriving at the span. According to Li most trees will stay close to the bank, thus;

$$N = NT / 2 \tag{5.9}$$

The probability that m trees will be trapped is;

$$Pm = [1-(1-PTm)^{[N-(m-1)]}]P(m-1) \tag{5.10}$$

On this basis the probability of a least m trees being trapped (for any m < N) can be estimated. In order to calculate Td and Dd there needs to be an estimate of the blockage area. It is assumed that debris elements stack up and that trees overlap by Db/2. Thus for m trees trapped the percentage of the waterway area which is blocked is

$$\%Blockage = \frac{m(\frac{1}{2}\pi Db^2/4)}{LsC} \times 100\% \tag{5.11}$$

Having estimated m and knowing Db the increase depth of water (wd) at the bridge is assumed to be

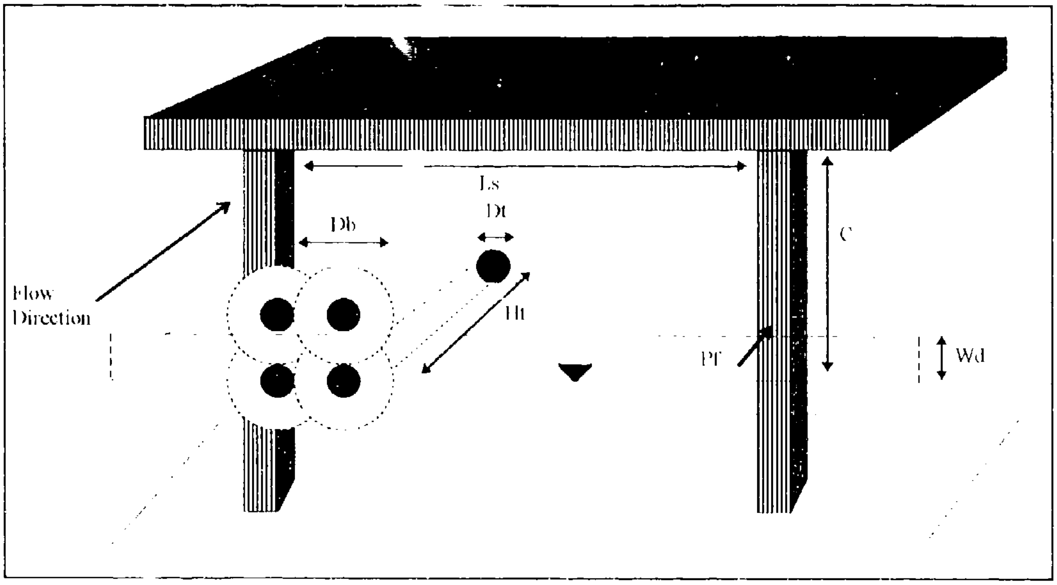
$$\Delta wd = \sqrt{m Dd} / 2 \tag{5.12}$$

The blockage generates a pressure force (Pf) which acts normal to the bridge is

$$Pf = \tfrac{1}{2}\gamma . m Db^2 / 4 \tag{5.13}$$

where γ is the specific weight of water

Figure 5.4 Schematic diagram of debr   umulation at bridge piers



5.2.3 Program construction and input varial   s

In essence the program runs the Simons and Li probability model and then calculates the potential pier scour due to a debris mat size based upon the blockage area assuming all the trees available in the reach upstream become trapped beneath a span.

Initially average (mid height) tree trunk diameter (Dt), a maximum tree diameter (Db), (ei root wad or canopy, whichever is the larger), and average tree height (Ht) values are entered. Next, the number of trees approaching the bridge span (NT) is entered. Although Simons and Li suggest using N   NT/   in the probability calculations, this model assumes that all the trees available in the upstream reach will pass through the span in question. However, the number of spans (S) between piers (P) that are set in the channel will normally be S   P+1 (counting the two spans between pier and river bank). It is therefore necessary, for an accurate assessment of blockage potential and debris related scour, to calculate probabilities for each span individually, perhaps using a simple division rule (N   NT / S) for N trees arriving at each span. It is left up to the user to make the appropriate adjustments for each span. NT can either be estimated in the field and entered as a total potential tree supply or can be estimated through calculation of potential bank failure in the upstream reach. To calculate the latter estimate a riparian tree density value is required, the length of the reach in question and the potential bank failure width. The failure width value can be determined using an appropriate bank stability model such as BURBANK (Burgi, 1995). The potential number of trees that will reach the span is then calculated as:

tree density x failure width x reach length x 2 (two banks)

Finally, the bridge pier diameter (D), span between piers (ls) and average flow depth (Y) values are entered.

Calculations then proceed as follows:

1) If tree height is less than the pier spacing the probability of the first tree becoming caught is calculated, followed by the probability of the next tree becoming caught consecutively. This is repeated for n trees up to NT.

In the calculation of trapping potential it is considered that, the use of the ratio of tree area to the entire area under the span as suggested by Simons and Li, is somewhat inappropriate as tree capture is dependant only upon the length of span and diameter of tree given that the water level is constant. Deck elevation above the water (C) has therefore been substituted with maximum tree diameter (Db) in this model.

2) If tree height is greater than span width it is assumed, as outlined in the Simons and Li model that at least one tree will become trapped and thus all subsequent trees arriving at the span will also be caught.

3) The percentage of the channel cross sectional area that is blocked if all the trees supplied to the reach become trapped is calculated as outlined in the theoretical model (see figure 5.4) for Ht < ls. However if Ht > ls Dt is substituted for Db and the blockage area is calculated as :

(((square root x blockage area) blockage depth (assuming debris builds up as a square) x tree height) / (span width x flow depth)) x 100 %

This calculation assumes that for Ht > ls all trees will build up in a square formation, but at 90 degrees to the flow direction, as oppose to parallel with the flow when Ht < ls.

4) The hydrostatic pressure force on each pier per unit width is calculated as :

pressure force = bulk weight of water x blockage depth x 1 (unit width) x (blockage depth / 2).

5) Bridge pier scour with the debris accumulation is then calculated using the Melville and Dongol model. If Ht > ls the debris raft diameter is taken as the square root of the blockage area (assuming debris build-up is in a square). If Ht < ls debris raft diameter is assumed to be Ht because the debris is aligned parallel with the direction of flow. The scour depth is calculated using the base value of 2.4D. If the additional multiplying factors are required they

must be added by hand, referring to the graphs and tables supplied in Melville and Dongols' 1988 paper. Factors which reduce this value are applied where clear-water scour conditions exist (K_I), the flow depth is relatively shallow (K_y), and the sediment is relatively large (K_d). If piers are not cylindrical two additional factors are required; a shape factor (K_s) and an alignment factor (K_α). The following data are required to calculate these additional factors : mean approach velocity for the design flood (U); median particle size (d_{50}); standard deviation of the particle distribution (σ_g) = d_{84}/d_{50}; pier diameter (D); angle of flow attack; pier dimensions; and pier shape.

It should be noted that the formula, developed by Melville and Dongol for calculating debris related pier scour, was only developed for floating debris accumulations. However, it is considered by the authors that this formula can be extended to debris accumulations which have their base resting on the channel bed, as the critical factor in the calculation method is an effective pier diameter, which is, in any case, extended to the channel bed in the situation where the debris is floating.

6 CONCLUSIONS

The following conclusions can be drawn from the results obtained in this study :

1) The sources of major debris input to the channel network can be predicted by mapping the areal distribution of reaches with wooded riparian zones which are also laterally unstable or actively migrating.

2) The impact of debris jams in sand-bed rivers is different to that in gravel bed rivers as distinct log steps do not form.

3) Debris is a key factor controlling channel bed topography in sand-bed rivers, creating a more heterogeneous profile than found in debris free reaches. This is important for creating productive aquatic habitat.

4) Debris jams in sand-bed rivers are stable in the short term (1 yr.). But total residence times may be longer in gravel-bed rivers.

5) Reconnaissance evidence suggests that jam forms change in a predictable manner downstream through the channel network.

6) Debris jams dissipate flow energy, and reduce sediment routing rates, and therefore do not, exacerbate channel bed degradation problems. The distribution of sedimentation and scour associated with debris jams appears have an geomorphically explainable distribution when related to drainage basin area.

MANAGEMENT RECOMMENDATIONS

The following management recommendations have been made based upon the findings discussed herein:

1) Basin-wide debris clearance is unnecessary and may have detrimental affects. Debris does not appear to exacerbate the degradation problem encountered in the bluff-line streams and can even accelerate aggradation processes locally.

2) Debris should be left in place or even introduced into the channel if the management aim is habitat enhancement

3) Debris jams may have to be removed over the mid-range of basin sizes if the primary management aim is to reduce bank erosion

4) In rivers with run-of-river structures, excessive debris loads, may be partially reduced through control of upstream channel degradation and outer bank erosion

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APPENDIX 1

Large Woody Debris Management Program (Version 1) User Manual

Introduction

This manual describes version 1 of an on-going developmental program designed to aid engineers, geomorphologists and planners with management of woody debris in river channels throughout the catchment network.

The executable program for this model (DEBRIS) is written in C++ and is contained on the supplied MS-DOS formatted disk, labelled "DEBRIS & DPROB". The file called debris.cpp contains the program source code.

This program may be freely copied, but the source code may not be distributed to other parties. The author accepts no responsibility or liability resulting from the use of the program.

Installation

To install DEBRIS and DPROB insert the supplied disk into the A drive and type a:install. A directory called LWD will then be created on the C drive and the files debris.exe and dprob.exe copied into it.

Running the program

It should be noted that the required units for data entry in this program are SI (millimetres, metres, kilometres).

Run the program by typing "**debris**" from the LWD directory.

1) Enter a **file name** for the output text file e.g. "basin1.txt"

2) Enter the **riparian vegetation type** that is predominantly found along the reach of river in question. A simple distinction is made between wooded and agricultural. Enter "**w**" or "**a**"

If "agricultural" is entered the next prompt will ask if you wish to run the program again. Type "**y**" or "**n**".

4) If "w" is entered the next prompt will ask you to enter the **average riparian tree height** (metres).

5) Enter the **drainage basin area** (kilometres square) of the reach in question. This parameter is used to calculate an average channel width based upon a selected width function.

6) **Average channel width** can either be calculated using the default function, derived by Schumm, Harvey and Watson (1984), which is appropriate for channels in northern Mississippi, or the user can enter their own function. The default function is :

$$\text{average channel width} = [(46.77 \times Da^{0.24}) + (15.7 \times Da^{0.39})] / 2$$

Where Da = drainage basin area in square miles. This is converted to square kilometres by the program.

Select "**n**" to use the default function or select "y" to enter a new function. A new function takes the form of :

$$\text{average channel width} = \text{constant (a)} \times \text{drainage area}^{\text{constant (b)}}$$

The user is prompted first for **constant a**, then for **constant b** both of which must be numerical values from functions developed in SI units. Note constant b must be less the 1 else the program will crash.

7) Enter the channel bed **sediment D_{50}** (mm).

9) The user will then be asked whether they wish to run the program again. Enter "**y**" or "**n**". If "y" is typed the program will run again and return to the prompt asking for the riparian vegetation type. If "**n**" is selected the program will terminate and return to the operating system.

Program Output

The results are written to an output file which has the file name specified by the user. The output file is created in the LWD directory. If the program is unable to create the output file an error message will appear reading "Error opening file". If this happens the program should be terminated.

The output text file can be viewed, once the program has been ended, in any text editor or in a word processor such as Word or Word Perfect.

Successive outputs from each program will be added sequentially to the same text file. Program runs are distinguished by a numbered header (i.e. program run number 1........ program run number 2....... etc.).

Results have the following standard output format:

1) A program run and " Woody Debris Management Output" header.

2) A list of the input parameters including the calculated channel width.

3) A description of the debris jam classification type chosen and the geomorphological impact of debris jams for that reach. Management recommendations (displayed in capital letters) based upon the geomorphological processes

Test Cases

These examples are provided to ensure that the user is familiar with the procedures used to run the program, and to check that the supplied program is working correctly

1. Start the program by typing "debris" from the LWD directory.

2) Enter an output file name e.g. "basin1.txt"

3) Enter the following values :

	run 1	run 2	run 3	run 4
riparian vegetation	w	w	w	a
average tree height	10	10	10	-
drainage basin area	40	200	20	-
alternative width function ?	n	n	y	-
constant a	-	-	10	-
constant b	-	-	0.30	-
sediment type	0.25	1.0	2.6	-

7) Leave the program and run a text editor or word processor to view the output file.

8) The output for runs 1 to 4 should be as follows:

Program run number 1

WOODY DEBRIS MANAGEMENT OUTPUT

The riparian land type in the chosen reach is wooded

The drainage basin area is 40 kilometres square

The average riparian tree height is 10 metres

The sediment D50 in this reach is 0.25 mm

Channel width calculated using the Schumm, Harvey & Watson formula
The average channel width in this reach is 20.7052 metres

GEOMORPHOLOGICAL IMPACT OF WOODY DEBRIS IN THE SELECTED REACH

Average debris length is less tham 0.6 times the channel width.
Large Woody Debris (LWD) input mechanisms to this reach will include floatation of debris from upstream reaches, tree toppple due to bank failure in unstable reaches, and also due to bank failure in bend apices if the channel in this reach is meandering. Although failed trees are likely to enter the channel at 90 degrees to the channel, flows will be competant enough to rotate debris so that FLOW PARALLEL LWD debris jams form. LWD will also be transported downstream is high flows, and deposited against the bank-base on the outside of meander bends or at bridge piers and other run-of-the-river structures.
(See Wallerstein & Thorne (1994), for a complete description of FLOW-PARALLEL type jams)
The negative geomorphological impact of this type of jam in terms of bank erosion and bed scour is minimal. Bank toes may even be stabilised by debris build-up
Debris may also initiate or accelerate the formation of mid-channel and lateral bars.

WOODY DEBRIS MANAGEMENT RECOMMENDATIONS

DEBRIS CLEARANCE UNNECESSARY IF IT IS KEYED INTO PLACE AT BANK TOES OR IN BARS.
BRIDGES AND OTHER RUN-OF-THE-RIVER STRUCTURES SHOULD BE MONITORED FOR JAM BUILD-UP
(See Melville & Dongol (1992) for a method of calculating pier scour due to debris build-up
and Callandar (1980) for a probability based method of predictng debris build-up at bridge
piers, and formula for calculating the increased pressure force and flow afflux due to debris)
FLOATING DEBRIS MAY ALSO PROVE TO BE A DANGER TO SMALL BOATS

REFERENCES

CALLANDER (1980), Fluvial processes occuring at bridge sites,
MSc. Thesis, Colorado State University.

MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,
Journal of Hydraulic Engineering, ASCE, vol 118, no. 9

SCHUMM, HARVEY & WATSON (1984), Incised Channels : Morphology, Dynamics and Control,
Water Resources Publication, pp. 111-159

WALLERSTEIN & THORNE (1994), Impact of in-channel organic debris on fluvial process
and channel morphology, Yazoo Basin, Mississippi, University of Nottingham, Department
of Geopraphy, working paper no. 29

Program run number 2

WOODY DEBRIS MANAGEMENT OUTPUT

The riparian land type in the chosen reach is wooded

The drainage basin area is 200 kilometres square

The average riparian tree height is 10 metres

The sediment D50 in this reach is 1 mm

Channel width calculated using the Schumm, Harvey & Watson formula
The average channel width in this reach is 33.2626 metres

GEOMORPHOLOGICAL IMPACT OF WOODY DEBRIS IN THE SELECTED REACH

Average debris length is less than 0.6 times the channel width
Large Woody Deb[illegible] (LWD) input mechanisms to this reach will include
floatation of debris from upstream reaches, tree topple due to bank failure
in unstable reaches, and also due to bank failure in bend apices if the
channel in this reach is meandering. Although failed trees are likely to enter
the channel at 90 degrees to the channel, flows will be competant enough to rotate
debris so that FLOW PARALLEL LWD debris jams form. LWD will also be transported
downstream is high flows, and deposited against the bank base on the outside of
meander bends or at bridge piers and other run-of-the river structures.
(See Wallerstein & Thorne (1994), for a complete description of FLOW-PARALLEL type jams)
The negative geomorphological impact of this type of jam in terms of bank
erosion and bed scour is minimal.Bank toes may even be stabilised by debris build-up
Debris may also initiate or accelerate the formation of mid-channel and lateral bars.

WOODY DEBRIS MANAGEMENT RECOMMENDATIONS

DEBRIS CLEARANCE UNNECESSARY IF IT IS KEYED INTO PLACE AT BANK TOES OR IN BARS.
BRIDGES AND OTHER RUN-OF-THE-RIVER STRUCTURES SHOULD BE MONITORED FOR JAM BUILD UP
(See Melville & Dongol (1992) for a method of calculating pier scour due to debris build-up
and Callandar (1980) for a probability based method of predicting debris build up at bridge

piers, and formula for calculating the increased pressure force and flow afflux due to debris)
FLOATING DEBRIS MAY ALSO PROVE TO BE A DANGER TO SMALL BOATS

REFERENCES

CALLANDER (1980), Fluvial processes occuring at bridge sites,
MSc. Thesis, Colorado State University.

MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,
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SCHUMM, HARVEY & WATSON (1984), Incised Channels : Morphology, Dynamics and Control,
Water Resources Publication, pp. 111-159

WALLERSTEIN & THORNE (1994), Impact of in-channel organic debris on fluvial process
and channel morphology, Yazoo Basin, Mississippi, University of Nottingham, Department
of Geography, working paper no. 29

Program run number 3

WOODY DEBRIS MANAGEMENT OUTPUT

The riparian land type in the chosen reach is wooded

The drainage basin area is 20 kilometres square

The average riparian tree height is 10 metres

The sediment D50 in this reach is 2.6 mm

Channel width calculated using the following formula

width = (drainage area ^ 0.3) x 10

The average channel width in this reach is 24.5646 metres

GEOMORPHOLOGICAL IMPACT OF WOODY DEBRIS IN THE SELECTED REACH

Average debris length is less than 0.6 times the channel width.
Large Woody Debris (LWD) input mechanisms to this reach will include
floatation of debris from upstream reaches, tree toppple due to bank failure
in unstable reaches, and also due to bank failure in bend apices if the
channel in this reach is meandering. Although failed trees are likely to enter
the channel at 90 degrees to the channel, flows will be competant enough to rotate
debris so that FLOW PARALLEL LWD debris jams form. LWD will also be transported
downstream is high flows, and deposited against the bank-base on the outside of
meander bends or at bridge piers and other run-of-the-river structures.
(See Wallerstein & Thorne (1994), for a complete description of FLOW-PARALLEL type jams)
The negative geomorphological impact of this type of jam in terms of bank
erosion and bed scour is minimal.Bank toes may even be stabilised by debris build-up
Debris may also initiate or accelerate the formation of mid-channel and lateral bars.

WOODY DEBRIS MANAGEMENT RECOMMENDATIONS

DEBRIS CLEARANCE UNNECESSARY IF IT IS KEYED INTO PLACE AT BANK TOES OR IN BARS.
BRIDGES AND OTHER RUN-OF-THE-RIVER STRUCTURES SHOULD BE MONITORED FOR JAM BUILD-UP
(See Melville & Dongol (1992) for a method of calculating pier scour due to debris build-up
and Callandar (1980) for a probability based method of predicting debris build-up at bridge
piers, and formula for calculating the increased pressure force and flow afflux due to debris)
FLOATING DEBRIS MAY ALSO PROVE TO BE A DANGER TO SMALL BOATS

REFERENCES

CALLANDER (1980), Fluvial processes occuring at bridge sites,
MSc. Thesis, Colorado State University.

MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,
Journal of Hydraulic Engineering, ASCE, vol. 118, no. 9

SCHUMM, HARVEY & WATSON (1984), Incised Channels : Morphology, Dynamics and Control,
Water Resources Publication, pp. 111-159

WALLERSTEIN & THORNE (1994), Impact of in-channel organic debris on fluvial process
and channel morphology, Yazoo Basin, Mississippi, University of Nottingham, Department
of Geography, working paper no. 29

Program run number 4

WOODY DEBRIS MANAGEMENT OUTPUT

The riparian land type in the chosen reach is agricultural

Because the immediate riparian zone is agricultural land, or the reach
selected is in open water woody debris input through tree blowdown or
death, beaver activity and channel bank erosion will be minimal
Substantial debris jams are therefore unlikely to build up in the reach

WOODY DEBRIS MANAGEMENT RECOMMENDATIONS

DEBRIS JAMS NOT PRESENT IN REACH, DEBRIS REMOVAL UNECESSARY.
SMALLER DEBRIS MAY BE INPUT FROM UPSTREAM REACHES HOWEVER AND DEBRIS
BUILD-UP AT STRUCTURED SUCH AS BRIDGE PIERS, LOCKS, DAMS AND WIERS, SHOULD BE MONITORED.
IF CHANNEL BED IS UNSTABLE AND HAS A SAND SEDIMENT LOAD CONSIDERATION
SHOULD BE GIVEN TO ARTIFICIAL DEBRIS INPUT ON THE FEQUENCY OF THE EXPECTED
RIFFLE SPACING TO VARY CHANNEL BED TOPOGRAPHY AND THUS IMPROVE AQUATIC HABITAT
AND ENHANCE CHANNEL STABILISATION THROUGH SEDIMENT RETENTION
LARGE WOODY DEBRIS CAN ALSO BE KEYED INTO THE OUTSIDE ERODING BANK OF ACTIVE
MEANDER BENDS TO REDUCE LOCAL NEAR-BANK SHEAR-STRESS

REFERENCES

CALLANDER (1980), Fluvial processes occuring at bridge sites,
MSc. Thesis, Colorado State University.

MELVILLE & DONGOL (1992), Bridge Pier Scour with Debris Accumulation,
Journal of Hydraulic Engineering, ASCE, vol. 118, no. 9

SCHUMM, HARVEY & WATSON (1984), Incised Channels : Morphology, Dynamics and Control,
Water Resources Publication, pp. 111-159

WALLERSTEIN & THORNE (1994), Impact of in-channel organic debris on fluvial process
and channel morphology, Yazoo Basin, Mississippi, University of Nottingham, Department
of Geography, working paper no. 29

APPENDIX 2

Debris at Bridge Pier Prediction Program (Version 1.0) User Manual

Introduction

This manual describes a probability based model for predicting the build-up of debris at bridge piers. It is based upon two theoretical models developed by Melville and Sutherland (1992) and Simons and Li (in Callander, 1980).

The executable program for this model (DPROB) is written in C++ and is contained on a MS-DOS formatted disk, labelled "DEBRIS & DPROB". The file called dprob.cpp contains the program source code.

This program may be freely copied, but the source code may not be distributed to other parties. The author accepts no responsibility or liability resulting from the use of the program.

Installation

To install DEBRIS and DPROB insert the supplied disk into the A drive and type a:install. A directory called LWD will then be created on the C drive and the files debris.exe and dprob.exe copied into it.

Running the program

The required units for data entry in this program are SI.

Run the program by tying "**dprob**" from the LWD directory.

1) Enter a **file name** for the output text file e.g. "results1.txt".

2) Enter the average riparian **tree trunk diameter** (m).

3) Enter the average maximum root wad or canopy diameter (whichever is larger), (m).

4) Enter the average riparian **tree height** (m).

5) The **number of trees approaching the bridge span** can be either be entered as a total value from upstream reach observations, or can be estimated through the input of a riparian tree density, bank top failure width and reach length. Type "**1**" for an estimated value. Type "**2**" to enter an observed value.

5a) If "2" is typed enter the **number of trees available** in the upstream reach.

5b) If "1" is typed :

- i) Enter average **riparian tree density** (m/m).
- ii) Enter **bank top failure width** (m). This can be calculated using an appropriate bank stability model
- iii) Enter **reach length** (m).

6) Enter **bridge pier diameter** (m).

7) Enter **distance between bridge piers** at water level (m).

8) Enter **flow depth** immediately upstream of bridge (m).

9) Enter "**y**" to input new values or enter "**n**" to end the program.

Program Output

The results from DPROB are written an output file which has the file name specified by the user during the first program run. The output files will be created in the LWD directory. If the program is unable to create the output file an error message will appear reading "Error opening file". If this message appears the program should be terminated.

The output text files can be viewed, once the program is terminated, in a text editor or word processor such as Word or Word Perfect.

Successive outputs from each program run will be added sequentially to the same text file. Program runs are distinguished by a numbered header (i.e. program run number 1; program run number 2; ....etc.).

Results have the following standard output format:

1) A "Debris at Bridge Pier Calculations" header.

2) A list of the input parameter values, including the calculated number of trees available in the upstream reach, if that option was selected.

3) The probability results. If the average tree height (Ht) is greater than the distance between the bridge piers (ls) the probability of at least one tree becoming trapped is assumed to be 1. If Ht < ls the probability of each tree in the upstream reach successively becoming trapped is displayed up to the total, Nt trees.

4) Bridge pier scour calculations. These values are calculated assuming that all, NT, trees are caught to give a worst case scenario. The following values are then displayed:

i) The probability of NT trees becoming caught.

ii) The calculated debris raft depth.

iii) The percentage of the channel cross-section blocked by debris.

iv) Bed scour due to the pier alone (using 2.4 x D).

v) Bed scour due to the pier and debris accumulation.

vi) The hydrostatic pressure force on the pier due to the debris accumulation.

Test Cases

These examples are provided to ensure that the user is familiar with the procedures necessary to run the programs, and to check that the supplied program is working correctly.

1) Start the program by typing "**dprob**" from the LWD directory.

2) Enter an output file name, e.g. "results.txt".

3) Enter the following values :

	run 1	*run 2*	*run 3*	*run 4*
tree trunk diameter	0.5	0.5	0.5	0.5
max. tree diameter	2	2	2	2
average tree height	6	6	6	6
tree estimation option	2	2	1	1
tree density	-	-	0.025	0.0125
reach length	-	-	100	100
failure width	-	-	2	4
number of trees	10	10	-	-
pier diameter	1	1	1	1
pier spacing	6	20	30	40
flow depth	6	6	6	6

4) Exit the program and view the results in an text editor or word processor.

5) The results in runs 1 to 4 should read as follows:

Program run number 1

DEBRIS AT BRIDGE PIER CALCULATIONS

The tree trunk diameter is 0.5 metres
The tree root wad/canopy diameter is 2 metres
The average tree height is 6 metres
The observed number of trees in the upstream reach is 10
The bridge pier diameter is 1 metres
The length between bridge piers is 6 metres
The flow depth is 6 metres

Bridge pier scour output :
The following values have been calculated by assuming all 10 trees are caught at the bridge
The probability of at least 1 out of 10 trees becoming trapped is 100%
The debris raft depth is 0.99 metres
The percentage of the channel cross-section blocked is 16.51 %

Scour calculation are derived from a model developed by Melville and Dongol (1992)

Bed scour due to the pier = 2.4 metres
Bed scour due to the pier and debris accumulation = 3.43 metres
The pressure force normal to the bridge pier is 4.81e+03 N/m unit width

Program run number 2

DEBRIS AT BRIDGE PIER CALCULATIONS

The tree trunk diameter is 0.5 metres
The tree root wad/canopy diameter is 2 metres
The average tree height is 6 metres
The observed number of trees in the upstream reach is 10
The bridge pier diameter is 1 metres
The length between bridge piers is 20 metres
The flow depth is 6 metres
==
Probability Results
The probability of at least one out of 10 trees becoming trapped is 0.33
The probability of 2 trees being trapped is 0.1033
The probability of 3 trees being trapped is 0.0304
The probability of 4 trees being trapped is 0.0083
The probability of 5 trees being trapped is 0.0021
The probability of 6 trees being trapped is 0.0005
The probability of 7 trees being trapped is 8.6762e-05
The probability of 8 trees being trapped is 1.3338e-05
The probability of 9 trees being trapped is 1.4826e-06
The probability of 10 trees being trapped is 8.9977e-08
==

Bridge pier scour output :
The following values have been calculated by assuming all 10 trees are caught at the bridge
The probability of 10 trees becoming trapped is 8.9977e-08
The debris raft depth is 3.96 metres
The percentage of the channel cross-section blocked is 13.08 %

Scour calculation are derived from a model developed by Melville and Dongol (1992)

Bed scour due to the pier = 2.4 metres
Bed scour due to the pier and debris accumulation = 6.52 metres
The pressure force normal to the bridge pier is 7.7e+04 N/m unit width

Program run number 3

DEBRIS AT BRIDGE PIER CALCULATIONS

The tree trunk diameter is 0.5 metres
The tree root wad/canopy diameter is 2 metres
The average tree height is 6 metres
The average tree density in the upstream reach is 0.025 trees per square metre
The upstream reach length is 100 metres
The channel failure width is 2 metres
The calculated maximum number of trees in the upstream reach is 10
The bridge pier diameter is 1 metres
The length between bridge piers is 30 metres
The flow depth is 6 metres
==
Probability Results
The probability of at least one out of 10 trees becoming trapped is 0.2329
The probability of 2 trees being trapped is 0.0506

The probability of 3 trees being trapped is 0.0102
The probability of 4 trees being trapped is 0.0019
The probability of 5 trees being trapped is 0.0003
The probability of 6 trees being trapped is 4.2879e-05
The probability of 7 trees being trapped is 5.0811e-06
The probability of 8 trees being trapped is 4.7283e-07
The probability of 9 trees being trapped is 3.0778e-08
The probability of 10 trees being trapped is 1.0534e-09

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Bridge pier scour output :
The following values have been calculated by assuming all 10 trees are caught at the bridge
The probability of 10 trees becoming trapped is 1.0534e-09
The debris raft depth is 3.96 metres
The percentage of the channel cross-section blocked is 8.72 %

Scour calculation are derived from a model developed by Melville and Dongol (1992)

Bed scour due to the pier = 2.4 metres
Bed scour due to the pier and debris accumulation = 6.52 metres
The pressure force normal to the bridge pier is 7.7e+04 N/m unit width

Program run number 4

DEBRIS AT BRIDGE PIER CALCULATIONS

The tree trunk diameter is 0.5 metres
The tree root wad/canopy diameter is 2 metres
The average tree height is 6 metres
The average tree density in the upstream reach is 0.0125 trees per square metre
The upstream reach length is 100 metres
The channel failure width is 4 metres
The calculated maximum number of trees in the upstream reach is 10
The bridge pier diameter is 1 metres
The length between bridge piers is 40 metres
The flow depth is 6 metres

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Probability Results
The probability of at least one out of 10 trees becoming trapped is 0.1798
The probability of 2 trees being trapped is 0.0299
The probability of 3 trees being trapped is 0.0046
The probability of 4 trees being trapped is 0.0006
The probability of 5 trees being trapped is 7.5663e-05
The probability of 6 trees being trapped is 7.8817e-06
The probability of 7 trees being trapped is 6.7823e-07
The probability of 8 trees being trapped is 4.5245e-08
The probability of 9 trees being trapped is 2.0821e-09
The probability of 10 trees being trapped is 4.9626e-11

===

Bridge pier scour output :
The following values have been calculated by assuming all 10 trees are caught at the bridge
The probability of 10 trees becoming trapped is 4.9626e-11
The debris raft depth is 3.96 metres
The percentage of the channel cross-section blocked is 6.54 %

Scour calculation are derived from a model developed by Melville and Dongol (1992)

Bed scour due to the pier = 2.4 metres
Bed scour due to the pier and debris accumulation = 6.52 metres
The pressure force normal to the bridge pier is 7.7e+04 N/m unit width

Results Discussion

The probability of at least one tree snagging at the pier in run 1 is assumed to be 100% because the tree height (Ht) is equal to the pier spacing (ls), while probabilities for each of the ten trees arriving at the span in runs 2, 3 and 4 are calculated because Ht is less than ls.

The probabilities for the 10 trees in runs 2, 3 and 4 can be plotted as shown in figure A1 This plot shows how the probability of capture is dependant upon the maximum tree diameter to pier spacing ratio and demonstrates that the fall in probability of capture becomes asymptotically smaller as the clear water area between piers is reduced. In this instance the probabilities all tend towards zero because the difference between pier spacing and tree diameter is large.

Figure A1 Tree trapping probability plot